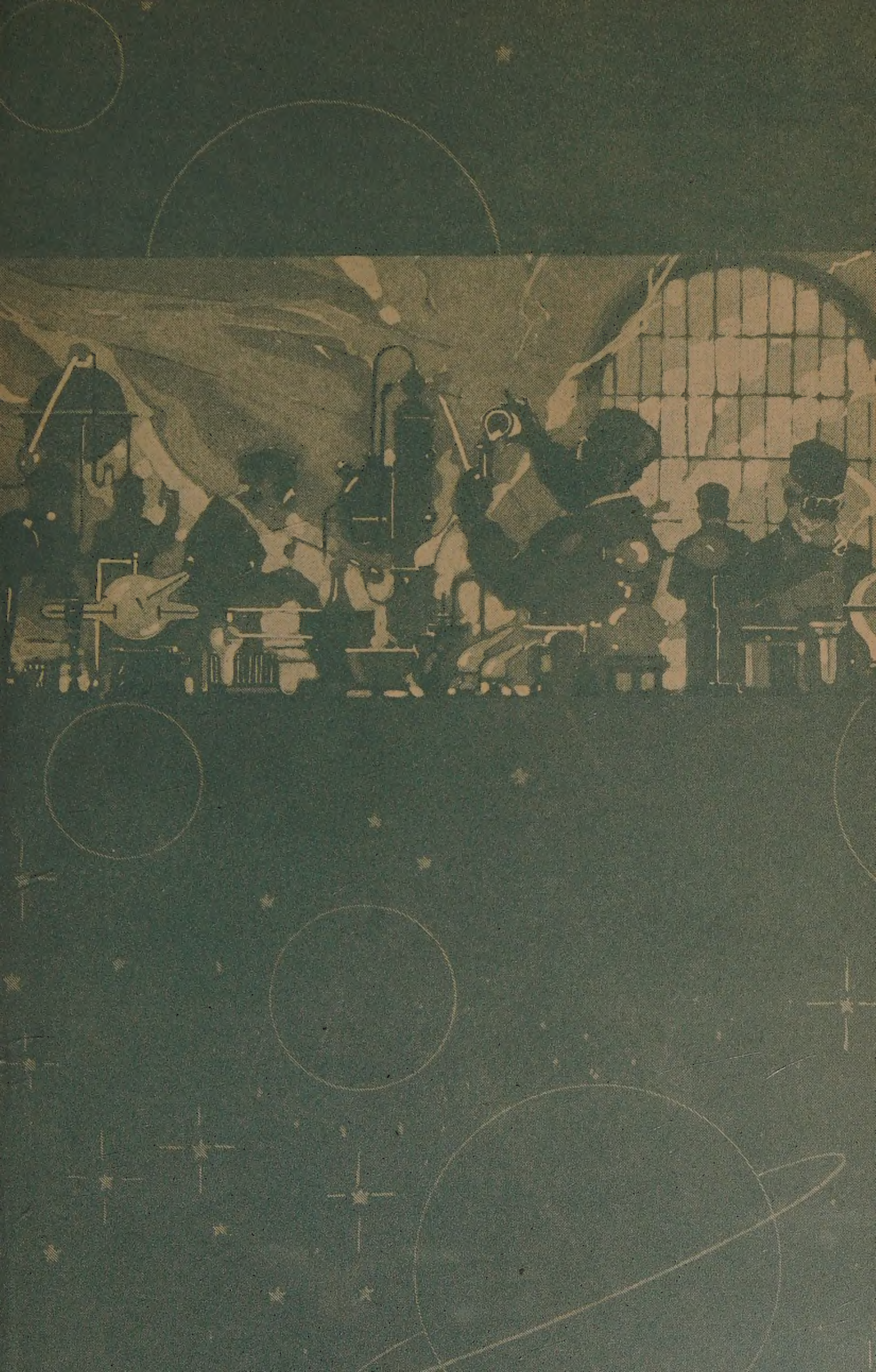
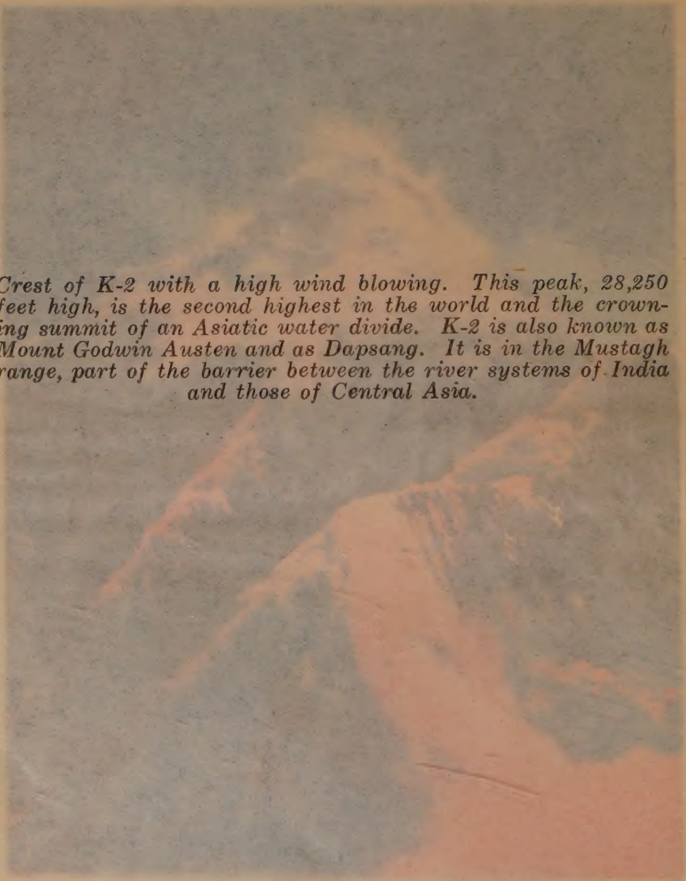
bie





Crest of K-2 with a high wind blowing. This peak, 28,250 feet high, is the second highest in the world and the crowning summit of an Asiatic water divide. K-2 is also known as Mount Godwin Austen and as Dapsang. It is in the Mustagh range, part of the barrier between the river systems of India and those of Central Asia.

POPULAR SCIENCE LIBRARY

EDITOR-IN-CHIEF
GARRETT P. SERVISS

AUTHORS
WILLIAM J. MILLER HIPPOLYTE GRUENER A. RUSSELL BOND
D. W. HERING LOOMIS HAVEMEYER ERNEST G. MARTIN
ARTHUR SELWYN-BROWN ROBERT CHENAULT GIVLER
ERNEST INGERSOLL WILFRED MASON BARTON
WILLIAM B. SCOTT ERNEST J. STREUBEL
NORMAN TAYLOR DAVID TODD
CHARLES FITZHUGH TALMAN
ROBIN BEACH

ARRANGED IN SIXTEEN VOLUMES
WITH A HISTORY OF SCIENCE, GLOSSARIES
AND A GENERAL INDEX

SUPPLEMENTED BY A LOOSE-LEAF VOLUME EMBODYING
THE MOST IMPORTANT DEVELOPMENTS IN SCIENCE,
ANNUALLY, FROM 1923 TO 1932

ILLUSTRATED

VOLUME FOURTEEN

P. F. COLLIER & SON COMPANY
NEW YORK

Copyright 1922
By P. F. Collier & Son Company

MANUFACTURED IN U. S. A.

PHYSIOGRAPHY

The Science of the Abode of Man

BY

WILLIAM BERRYMAN SCOTT
Blair Professor of Geology, Princeton University

P. F. COLLIER & SON COMPANY
NEW YORK

PREFACE

MODERN geography has frankly adopted the genetic standpoint. Not content to remain a purely descriptive science, as it had been since the days of Ptolemy and Strabo, it now endeavors to explain, as well as to describe the earth's surface features, by calling upon geology to show how those features were brought about. The processes of change to which our planet has been subjected for countless ages are so slow that they do not play a great part in that very brief space of the earth's life which we call human history. But the various parts of the land surface are, at the present day, in very different stages of topographical development and of very different dates of geological antiquity. Again, great regions owe their most characteristic features to the operation of certain agents of denudation which so predominate over the others as to reduce them to relative insignificance. North America, as far south as lat. 40 degrees N., and Europe down to lat. 50 degrees N. have so lately (from the geological point of view) been covered with vast sheets of flowing ice, like those of modern Greenland and Antarctica, that the glacial topography of those lands is the most striking and significant thing about them. Other lands are but recently elevated sea bottoms. In short, the reader should learn that the earth is not a finished product, but is still, as it has always been, in the process of slow and ceaseless change. An intelligent comprehension of the factors of this change and of the characteristic results which they bring about, is essential to a real understanding of geographical descriptions.

In this book I have endeavored, in simple and nontechnical language, to give the unprofessional reader a conception of the manner in which the earth's surface, as we know it, has been brought to its present condition, and to show how geographical conditions determine human interests. The earth is our home, and we must make the best of it, but in order to do that successfully it is essential to learn all that can be known of the laws that govern all things terrestrial, and to make use of those laws by adapting ourselves to them.

I have drawn upon a very wide range of books and monographs, and wish to express particular obligations to the works of the following writers: Miss Ellen Semple, Professors W. M. Davis, W. H. Hobbs, E. Huntington, D. W. Johnson, A. Penck, R. Pumpelly, R. D. Salisbury, A. Supan, and R. S. Tarr. To Professor Johnson and to the American Geographical Society my cordial thanks are due for their very kind permission to reproduce the model of Belgium and eastern France on pp. 86-7.

I am also under great obligations to my colleagues, Professors C. H. Smyth, E. G. Conklin, D. C. Munro, and A. F. Buddington, who have made very helpful suggestions, and to Professor W. J. Sinclair, who has kindly made the line drawings.

CONTENTS

CHAPTER PAGE

I. THE EARTH AS A WHOLE 9

II. AGENTS OF GEOGRAPHICAL CHANGE 33

III. LAND FORMS DETERMINED BY ROCKS 80

IV. THE TOPOGRAPHICAL EFFECT OF FAULTS AND JOINTS 114

V. THE GROUNDWATER 134

VI. THE DEVELOPMENT OF RIVERS 153

VII. THE DEVELOPMENT OF RIVERS—*Continued* . . 177

VIII. LAKES—PLAINS 198

IX. PLATEAUS AND MOUNTAINS 220

X. SEACOASTS AND ISLANDS 246

XI. THE OCEAN 283

XII. VOLCANOES AND EARTHQUAKES 312

XIII. CLIMATE 344

XIV. THE VEGETATION OF THE EARTH 363

LIST OF ILLUSTRATIONS

CREST OF K-2, WITH A HIGH WIND BLOWING . *Frontispiece*

FACING PAGE

LATERAL MORAINES OF FINDELEN GLACIER 32

GORNER GLACIER, LOOKING TOWARD THE BREITHORN . 33

GLACIAL HILL 56

YOSEMITE VALLEY FROM ARTIST'S POINT 57

TABLE MOUNTAIN, CAPETOWN, SOUTH AFRICA, WITH TABLECLOTH IN PLACE 82

DOWNFAULTED BLOCKS BETWEEN BRIGHT ANGEL AND TRINITY CREEKS, COLORADO CANYON 83

WEST SPANISH PEAK, COLORADO, SHOWING DIKES THAT CUT THROUGH THE EOCENE STRATA 104

CONTACT OF DEADWOOD QUARTZITE AND GRANITE ABOVE SHOSHONE DAM 105

COAL IN PLACE AT BOTTOM OF A SYNCLINAL TROUGH 128

DEVIL'S POST PILE, COMPOSED OF HEXAGONAL BASALTIC COLUMNS 129

HORIZONTAL SANDSTONE, RED DEER RIVER DISTRICT, CANADA 160

AUSABLE CHASM, NEW YORK, A YOUTHFUL RIVER-MADE GORGE 161

GRANITE CANYON FROM TONTO ESPLANADE, WITH TOWER OF SET IN THE DISTANCE 172

FLAT-TOPPED HILL, OR MESA, NEW MEXICO 173

VICTORIA FALLS FROM LIVINGSTON ISLAND, ZAMBEZI RIVER, SOUTH AFRICA 196

FACING PAGE
Palisades of the Hudson, Showing Rock that Has Weathered and Fallen 197
Coast of Newfoundland, With a "Stack," the Result of Waves Beating on the Cliffs . . . 256
Galveston Sea Wall, Constructed to Protect the City From Inundation 257
Live Craters of Java Volcanoes 320
Crater of Vesuvius From an Airplane 321

CHAPTER I

THE EARTH AS A WHOLE

IN form, the earth is approximately spherical, though the diameter from pole to pole is 26 miles less than the diameter at the equator, a difference which is really very slight, amounting to only little more than 1/153 part of the earth's radius, the distance from center to circumference. Then, too, the surface is irregular, involving further departure from the perfectly spherical form. The great depressions in which the sea is contained and the "platforms" which sustain the continents make up the major irregularities, while valley and plain, hill, plateau, and mountain range on the land and their counterparts on the sea floor are the minor irregularities. These irregularities seem very great to us and, in some instances, overwhelming and awe-inspiring, like the towering mass of the snow-capped Himalayas, or as the "deeps," the profoundest parts of the oceanic abyss, would appear, could the water be removed. Yet, in comparison with the size of the earth, the irregularities of its surface are exceedingly small and it is no exaggeration to say that, proportionately, the earth is smoother than an orange. In consequence of this relative insignificance of the earth's surface features, it is almost always necessary, in making relief models of any region, or geological cross sections, to exaggerate the vertical scale, since otherwise these surface features would hardly be visible. The model of the Yellowstone Park made by the Hayden Survey many years ago, when the park was 60 miles in each direction, was about 30 inches square, or about 2 miles to the inch horizontally. The greatest difference in altitude between any two points in the park is hardly more than 5,000 feet, say one mile, which would be half an inch on the horizontal scale. The great cañon, which holds the spectator in awe-struck silence, would, with equal vertical and horizontal scales, be a little groove about one-sixth of an inch deep. In order to make the topography of even that rough region visible at all, it was necessary to make the vertical scale four or five times as great as the horizontal. It is one of the hardest geographical lessons to learn, to appreciate the relatively small size of the topographical features of the land, which to us appear so great. But, in learning this lesson, it is necessary to remember that we are very small creatures ourselves, and the differences of height and form in the features of the land have exerted the most profound influence upon the course of human history and the development of civilization. In one sense, our mountains are molehills, but, in another, they are gigantic barriers.

With the material which is at present available, the area of the land in general and of particular parts of it can be given only approximately. Even in so well known and thoroughly mapped an area as that of Europe there are notable discrepancies between the maps of different powers which depict the same territories; and in making measurements of areas, which must largely be done from maps, the expansion and contraction of the paper, due to the state of atmospheric humidity, have a distinct effect upon the result. The errors from these sources are not very large, however; it is the unmapped portions of the polar regions, north and south, which cause the greatest uncertainties in such estimates.

The constitution of the earth's interior cannot be determined by direct observation, for artificial openings of any sort, save very near the surface, are as yet quite impracticable. The deepest boring that has ever been made but little exceeds a mile in depth, or only 1/4000 of the earth's radius. Such penetration, in proportion, would be less than 1/50 of an inch in a globe six feet in diameter; that is to say, it would not pass through the paper covering. While direct observation is thus impracticable, certain inferences may be confidently drawn from indirect data, physical and astronomical.

One fact thus determined is that the earth is very dense, its specific gravity, as a whole, being 5.1; that is to say, the earth is 5.1 times as heavy as a globe of pure water of the same size. Inasmuch as the surface rocks in the accessible part of the earth's crust have a specific gravity, on the average, of 2.5 and very rarely exceed 3, it is evident that the mass of the earth must be made up of some material much heavier than the surface rocks. It has been suggested that this material is chiefly iron, in the metallic state, or a mixture of iron and nickel, and the suggestion is strengthened by the phenomena of terrestrial magnetism. There is much reason to think that this inference is justified.

Another fact concerning the interior of the earth, which is so well established as to be well-nigh certain, is that that interior is highly heated. This is shown, not only by volcanoes, but by geysers, hot springs, and other vents, through which highly heated materials come up to the surface from unknown depths of the interior. These vents are arranged in linear series and, taken by themselves, might indicate high internal temperatures merely along certain lines and tell us nothing concerning the broad areas between those lines. On the other hand, deep mines and borings in all parts of the world invariably show rising temperature with increasing depth. The rate of temperature increase differs very much in different places, ranging from a maximum of 1 degree F. for every 20 feet of descent, as has been observed in some volcanic regions, to 1 degree F. for every 200 feet, the rate in the Calumet copper mine on Lake Superior. In the valley of the James River, North Dakota, are numerous artesian wells in a porous sandstone, which lies upon a floor of very ancient, crystalline rocks. This floor has a very irregular surface, while the surface of the sandstone is nearly flat; this implies that the thickness of the sandstone varies greatly from point to point. Temperature observations made in these wells showed very puzzling discrepancies, even in wells that are not far apart, until it was learned that the rate of temperature-increment depended upon the thickness of the sandstone, which is a bad conductor of heat. The nearer the ancient rocks approached the surface of the ground, or, what amounts to the same thing, the thinner the sandstone at any point, the more rapid the rise of temperature at that point.

The average from the hundreds of observations that have been made in various places would be about 1 degree F. for every 50 feet of descent, but, under such conditions, averages have no great significance. It should be noted that the steady increase does not begin immediately below the surface of the ground. There is, first, a layer in which a buried thermometer records a temperature that varies between day and night, following the changes in the air-temperature, with less extreme range. Below this is a layer which has no daily change of temperature, but a seasonal change, being warmer in summer and colder in winter, but with very much less range than in the air. The thickness of this layer varies with the range of temperature through the year; in the tropics it is only 3 or 4 feet thick, but the thickness increases with the distance of the place of observation from the equator. In the latitude of New York the two surface layers, that of daily and that of seasonal variation, are, taken together, about 50 feet thick. Next follows the layer of constant temperature, in which there is no change throughout the year, and below this begins the increase with descent.

The internal heat has but an extremely slight effect upon the climate of the earth's surface and, in dealing with climatic problems, the internal heat may be neglected. Likewise, for man in all stages of civilization, save the latest, the earth's internal heat has been of importance only as manifested at the surface in volcanoes, earthquakes, rising and sinking of the land, and the like.

With the advance of engineering technique, the earth's internal temperatures have taken on great practical importance, and the problems involved in deep mining and in tunneling high mountains have imperatively demanded a study of these temperatures and the laws which govern their distribution. It has been observed that the lines of equal temperature within the earth follow the irregularities of the surface, though with diminished steepness of slope. Much was learned of these lines in the construction of the Simplon tunnel, the latest and longest of the great tunnels that pierce the Alps. Owing to the unexpectedly high temperatures encountered, the project was almost abandoned and was successfully carried through only by the aid of compressed air, the expansion of which, when released, chills the air sufficiently for men to work. Yet this was no defense against the floods of hot water which were fatal to many of the workmen. The location of the tunnel was determined by the anticipated temperatures, which were estimated from the experience obtained in the St. Gotthard tunnel. The northern and southern entrances to the Simplon tunnel are more than 2,000 feet above sea level, which means a constant drain in the operating expenses, because of the steep grades of the approaches. Notwithstanding the increased cost of construction, it would have been more profitable in the long run to increase greatly the length of the tunnel and correspondingly reduce the grades at the approaches, and this course would have been followed, had it not been forbidden by the temperatures which would have been encountered at a lower level. Even at the selected level the heat proved to be greater than had been expected and, as stated above, almost wrecked the project.

The lines of equal temperature must rise into the continental masses from beneath the sea bed. Off the west coast of Africa the *Challenger* found a temperature of 33 degrees F. at a depth of more than 2,000 fathoms, while at a corresponding depth beneath the African plateau, which is 5,000 feet and more above the sea level, the temperature would be 356 degrees F., allowing the average rate of increment, 1 degree F. for every 50 feet of descent.

The practical importance of the earth's internal heat is by no means confined to tunnels. Whatever may be accomplished in the future, under present conditions the lower limit of possible mining is determined more by considerations of temperature than by any other factor. Needless to say, increasing depth is, in itself, a cause of increased cost of operation, not to mention the cost of sinking the shaft; but sufficiently rich ores, or other valuable material, will readily bear such increased expense. Temperatures in which men cannot work are prohibitory and increase of value will not meet the difficulty, and until some practicable method of cooling the deep-level workings and preventing the influx of hot water is devised, the temperature barrier will remain impassable. The future may also bring a means of utilizing the high temperatures beneath our feet and, if this should ever be accomplished, an immense fuel economy will be effected.

In attempting to explain the mechanism of the changes through which the earth has passed, such as the upheaval of mountain ranges, the formation of deep depressions in the land or in the bed of the sea, the folding of rocks, in which massive beds of hard rock are crumpled up like so many sheets of paper, the internal heat of the earth must be called upon. Although no human eye has ever witnessed these changes, either because they took place so long ago before mankind had been developed, or because they are so slow that they cannot be detected, there can be no question that the changes actually occurred. Similar events may even now be in progress, indeed, they probably are, but so slowly, or so far below the surface, that no observation of them is possible. Furthermore, the operations which are still going on and may be witnessed in one or other part of the earth, such as volcanoes, earthquakes, fracturing and dislocation of the rocks, rising and sinking of the sea coast, are all indisputably manifestations of the earth's internal heat, though the connection cannot always be proved.

The rocks which make up the outer portion of the earth, of indefinite and undetermined thickness, constitute the "crust" of the earth. By methods which the geologist took over from the miner and greatly extended, it is possible to determine the character and arrangement of the rocks for many thousands of feet below the surface, from observations made at the surface. A competent mining engineer can calculate the depth at which a bed of coal, or other economically valuable material, will be found under a given area, but there is a limit of a few tens of miles below which these methods cannot be successfully used. The term "crust" originally had a meaning which no longer attaches to it. When it was believed that the earth was chiefly composed of molten material, "a universal sea of fire," it was likewise believed that this molten mass was contained within a thin shell, which had solidified by cooling and was therefore a crust, just as a solid crust forms on the surface of a flowing lava stream. Now that the conception of a substantially fluid earth has been abandoned, the phrase "crust of the earth" has become merely a noncommittal term for the earth's outer portion.

While there is general agreement as to the density and high temperature of the earth's interior, there is great difference of opinion concerning the physical state of that interior, which is certainly subjected to pressures and probably also to temperatures far beyond anything in our experience. It would be profitless to enter here into any discussion of the theories which have been advanced concerning the physical state of the earth's interior. It must suffice to say that, as a whole, the earth is as rigid as a globe of steel. This is made plain by the phenomena of the tide and by the behavior of the earthquake waves which pass through the mass of the earth and are recorded by the seismographs at distant observatories. These are elastic waves, like the waves of sound, and their velocity depends upon the elasticity of the medium through which they pass. The velocity of these earthquake tremors increases with the depth of their path below the surface, down to a certain distance, below which it remains constant.

The earth's crust is made up of what the geologist calls rocks, and in geological language the term "rock" does not necessarily imply a hard and solid condition, as it does in ordinary speech. A bed of sand, clay, or gravel is as much rock as the hardest granite or marble. The study of rock formation, which is still going on, as it always has been throughout all of the earth's recorded history, shows us that the rocks fall into three categories or classes, in accordance with the manner in which they were made. We have, in the first place, the *igneous* rocks; that is to say, those which have solidified from a molten state. The lava of a modern volcano is an excellent illustration of what we mean by an igneous rock, though by no means all igneous rocks were poured out on the surface of the earth, as are the lavas and other volcanic rocks. Granite is a familiar instance of an igneous rock which solidified below the surface and is therefore called *plutonic.*

In the second place, we have the *sedimentary* rocks, also called *stratified, bedded, secondary,* or *derivative,* all synonymous terms. The sedimentary rocks are those which have been formed from the waste and disintegration of older rocks, either by chemical decomposition or merely mechanical breaking up. Material thus furnished by the decay of preceding rocks, is transported, it may be for vast distances, by the wind, by ice, or by running water, and finally comes to rest on land or in inland bodies of water, but chiefly upon the sea bottom, and is arranged in characteristic layers, beds, or strata, a necessary consequence of the manner in which sedimentary rocks are made and a feature which distinguishes them absolutely from the igneous rocks, which are never stratified, or divided into layers. Sand and sandstone, gravel and pudding-stone (or conglomerate), limestone, shale and the like are familiar examples of sedimentary rocks, both loose, like sand and clay, or consolidated and hard, like sandstone and limestone.

In the third place, we have the *metamorphic* rocks, which are, in a sense, intermediate between the other two classes. These are rocks which have been more or less profoundly reconstructed in place, chiefly by the agency of heat, without disintegration or decomposition, without the transportation and deposition of the rock material. Metamorphism results in increased hardnesss and, if it has been carried far, in the recombination and recrystallization of the components of the rock, so that new minerals are extensively generated. We find rocks which have undergone all stages of metamorphism and, in the case of those which have been greatly metamorphosed, it is often difficult, and sometimes impossible, to say whether the original rock, before metamorphism, was igneous or sedimentary; in either case the final result is almost the same. Familiar examples of metamorphic rocks are roofing slate and marble, which represent but a moderate degree of metamorphism. Gneiss and the crystalline schists result from an extreme degree of metamorphism.

The dry land is everywhere built up of rocks of these three classes and, so far as the accessible rocks are concerned, those of the sedimentary class are much the most largely represented. Among these sedimentary rocks of the land, those which were laid down in the sea and are therefore called *marine*, are the most abundant and the distribution of these marine sedimentary rocks shows that, with the exception of Africa, almost all parts of all the continents have been under the sea, at one time or another. This does not imply that the whole of any continent was all submerged at the same time, or, still less, that all the continents were totally submerged at the same time, so that there was no dry land. As far back as the history of the earth has been recorded in the rocks, there has always been land. Without land there would be no sedimentary rocks, because the material of which these rocks are made is furnished by the processes which operate on the land, not by those which are in operation on the sea bottom. With the sole exception of the rocks of organic origin which are formed in the sea—and it may be questioned whether these organic rocks form a real exception to the rule—the sedimentary rocks of marine origin were formed of material which came from the land. The very existence of these rocks implies the existence, at the same time, of dry land, which in most instances was not very far away.

THE PRESENT DISTRIBUTION OF LAND AND WATER

The exact area of the earth's land surface is not yet definitely known, chiefly because of uncertainty with regard to the polar regions, north and south. Just how large the Antarctic Continent is, can only be estimated, and the extent of land in the Arctic Archipelago also remains to be determined. However, when these regions shall have been fully explored and mapped, they cannot change very extensively the estimates that have been made. It is already possible to make quite a close calculation concerning the proportionate amounts of land and water on the surface of the globe. According to the latest estimates, the land forms about 29 per cent and the sea about 71 per cent of the earth's surface; or, in other words, there is about two and one-half times as much water as land. The land surfaces and the seas are very irregularly distributed over the earth; there is very much more land in the northern than in the southern hemisphere, but even in the northern hemisphere less than one-half of the surface is land. It is possible so to divide the globe into two equal hemispheres that almost all the land will be in one and the greater part of the sea in the other. In such a globe the north pole would be on the coast of France near the mouth of the Loire and the south pole in the neighborhood of New Zealand. In the southern hemisphere thus formed, the only land would be Australia, New Zealand and Antarctica and the southern tips of South America and Africa, while all the rest of the land would be included in the northern.

If a globe is so turned toward the spectator that only the northern hemisphere is to be seen and the north pole is in the center of the field of vision, it is seen that the land is grouped around the pole in three great masses and radiates from the pole in three lines. One of these lines is formed by the two American continents, the second by Europe-Africa, and the third by Asia-Australia. Starting, let us say, from the northern end of Bering Strait, one may travel to Cape Horn, the Cape of Good Hope, or to the southern end of Australia, without ever losing sight of land. This arrangement of the land in three radiating masses has been of the utmost importance in facilitating the distribution of terrestrial plants and animals over the surface of the earth and, no doubt, has also served greatly in permitting the dispersal of the races of men, so that all habitable parts of the earth had been reached and, in some degree, populated before the beginning of history. We speak of the discovery of America or Australia, but that means merely the finding of these lands by Europeans; they already had human inhabitants. The only large land area which, apparently, has never been inhabited by men is Antarctica, and it is difficult to see how men could have lived in that desolate land, even had they been able to reach it.

The arrangement of land and water on the earth's surface, irregular as it seems to be, results in a sort of compensatory balance. The antipodes of almost every spot on the land is in the sea; the converse statement would not be true, because of the vastly greater extent of the sea. A particularly well-defined example of this balance was brought to light only a comparatively few years ago, and that is in the area around the two poles. It had been generally believed that the Arctic Ocean was relatively shallow, but the soundings made by Nanssen and Peary have shown that that sea is of profound depth, comparable with that found in the other oceans. At the opposite end of the earth's axis lies Antarctica, a lofty land mass of approximately the same size as the Arctic Ocean; the depression in the north is balanced by the elevation in the south.

THE OCEANS

It is customary to divide the universal sea into five oceans, although the division is somewhat arbitrary and is rejected by some of the highest authorities in geography. The Arctic Ocean is manifestly a part of the Atlantic, while its connection with the Pacific is only by means of Bering Strait, which is but 40 miles wide, and the Indian Ocean is but a part of the Pacific. The old division is, nevertheless, a convenient one for purposes of description. By this scheme, we have the two main oceans, the Atlantic and Pacific, which extend from one polar sea to the other and are thus of similar length, but the Pacific has by far the larger area because of its great breadth. The third, or Indian, Ocean is but half this length, as Asia cuts off its northern extension. The Arctic Ocean is largely inclosed in land between North America and Asia, but the Antarctic sweeps around the earth almost without obstruction. In spite of this classification, which is convenient and useful, the sea is one and undivided. Every part of the sea is in communication with every other part, while the continents rise as great islands out of this universal sea. Indeed, the distinction between continent and island is merely one of size and so we find Australia and Antarctica treated now as islands, now as continents.

It is entirely owing to the irregularities of the earth's surface that there is any dry land at all; if all elevations were removed and all depressions filled, so that the earth had an actually smooth surface, there would be no land and the globe would be covered by a universal sea nearly two miles deep. This shows how greatly the water exceeds the land at the surface, and yet how insignificant is the whole amount of water in comparison with the size of the earth. The two miles depth of our supposed universal sea is but 1/2000 part of the earth's radius and therefore the water forms but a film, as it were, upon the surface.

The depth of water differs notably in different oceans and in different parts of the same ocean. The greatest depths, known as "deeps," occur as trough-shaped depressions, usually not very far from the land, and rivaling the highest mountains. Soundings of more than 5,000 fathoms have been made in the Pacific, which exceed the highest mountain peak, Mount Everest, of the Himalayas, in magnitude of departure from the sea level. The average depth of the sea is differently calculated by different geographers, because so much must be left to estimation. It is true that many lines of soundings have been carried across the oceans as surveys for the submarine cables, and various expeditions sent out by different governments have made thousands of soundings, but vast areas of the sea bottom are entirely unsounded and unknown. On the other hand, estimates are more trustworthy than they would be in the case of the land because of the general flatness of the ocean floor and the very gentle grades from one level to another. Mr. Mosely, of the *Challenger*, says that it was almost always practicable to make a close advance estimate of one day's soundings from a study of those made the day before. According to most authorities, the average depth of the sea is about 2,000 fathoms. Each of the oceans fills a depression in the surface of the globe, which, from our standpoint, may be called profound, but like all the other surface features, such profundity is a small matter in proportion to the size of the earth.

In very many instances, the true oceanic depression, or basin, begins at the 100-fathom line, which is generally taken as the boundary between deep and shallow water. There is nothing magical about the 100-fathom line, nor is the selection of it merely an arbitrary one; it simply registers the fact that at very many places on the sea floor the steep plunge into deep water begins at or near this line and it is convenient to use the same line elsewhere. Out to that line the water deepens very gradually from the shore and the change to a steep slope is usually abrupt, but by no means always. Off the west coast of Ireland the change begins at the 200-fathom line; and at the mouth of the Congo, on the west coast of Africa, it is at the 50-fathom line. Off the coast of the Carolinas, in the eastern United States, the sea bottom slopes gradually from low-water mark to profound depths, without abrupt change at any point. Generally speaking, the 100-fathom line may be taken as the line where the ocean basin begins and therefore marks the true edge of the continental uplift, or platform, as it is usually called. The belt of shoal water between the shore and the 100-fathom line is the submerged margin of the continent, the breadth of which varies greatly in different places and along different coasts. Off the eastern coast of the United States, for most of its length, this shoal-water belt is about 100 miles wide, and there is much reason to believe that in past geological ages the dry land has extended out to this line. The submerged channel of the Hudson river has been traced by soundings all the way across the continental shelf to the beginnings of deep water. Rivers do not excavate trenches on the sea floor and when the Hudson made that cañon, the now submerged shelf must have been land. Paradoxical as it seems, the real mouth of the river was once 120 miles southeast of Sandy Hook and is now but 6 miles below Albany, where the bar marks the meeting of the river with the tidal estuary. The river mouth has thus been shifted northward for more than 250 miles, the lower valley completely submerged and the middle valley "drowned," i. e., invaded by the sea and converted into a tidal estuary. All this change, of course, involves a great depression of the coast, of which there is much evidence of a different kind.

On the Pacific side of both North and South America, conditions are very different; on that coast there is no wide belt of shoal water, deep water beginning within ten miles of the shore. This very striking difference between the Atlantic and Pacific sides of the same continent, of course, indicates important differences in the history of the two regions, such as it is the task of geology to reconstruct.

THE LAND

The average elevation of the continents above sea level has been variously estimated, because of uncertainty as to the exact altitude of vast areas which are either unexplored, like much of the interior of Brazil, or have been lately brought to light, like the Antarctic Continent. Excluding the latter, one of the latest estimates of this average is 2,275 feet (700 meters). Antarctica, from the distribution of barometric pressures, is estimated at the remarkable figure of 6,500 feet, and, if confirmed, this will raise the average for all lands to 2,600 feet.

These averages really tell us very little, as the mean height between a narrow, lofty mountain range and a broad, low-lying plain has no great significance. More instructive is the curve which has been worked out by various geographers, especially by Professor Penck, of Berlin, which shows the percentages of land above certain heights and of water below given depths. For example, the area of land which is more than 10,000 feet above sea level is only about 1 per cent of the total surface of the earth (not merely of the land surfaces); only 5½ per cent of the total surface is higher than 3,250 feet (1,000 meters); and 10½ per cent is below 750 feet. Comparing these with the proportions of the sea bottom at various depths, we find that the submerged continental shelf between the shore and the 100-fathom line is between 4 and 5 per cent of the earth's surface; 23 per cent is between 2,000 and 2,750 fathoms, and 2 per cent between 2,000 and 5,500 fathoms. These figures clearly show how much greater is the depression of the sea floor below the sea level than the elevation of the continents above it.

The ocean basins and the continental platforms constitute, in Professor Salisbury's phrase, relief features of the first order of magnitude, while those of the second order are the topographical features of the land surface and the bottom of the sea. Plains, plateaus, and mountains are land features of the second order, while minor topographical elements, like hills, valleys, undulations, and the like, may be grouped in the third order. These features will be systematically dealt with in subsequent chapters. They are mentioned here merely to give a general survey of the lands.

Plains are the low-lying parts of the land, but they may gradually rise to great heights, as the Great Plains of the United States do. By imperceptible gradations they rise from little above sea level on their eastern border to 5,000 feet and more at the foot of the Rocky Mountains. The plateau or table-land is an elevated plain, but the distinction is not merely one of altitude, for some plains are higher than some plateaus, as the western part of the Great Plains is more than twice as high as the Cumberland Plateau of Kentucky and Tennessee. The difference is that, on one side at least, the plain is abruptly demarcated by higher, the plateau by lower land. From Long Island to the Gulf of Mexico, the eastern shore of the United States is formed by the low-lying, flat, and featureless Coastal Plain, which is bounded on the inland side by the Piedmont Plateau, of no great height and, if the sea came to its foot, it would be called a plain. It is quite abruptly demarcated from the present Coastal Plain and its edge forms the line at which the streams crossing the plateau break into rapids and cascades. This was very early detected by the European settlers, who called it the *Fall Line* and built many important towns like Trenton, Philadelphia, Wilmington, Columbia, at this line as marking the head of river navigation. The distinction between plateau and mountain is not always obvious, but one characteristic difference may be noted, which is that the summit area of the plateau is always considerable and may be very great, while that of the mountain is small in proportion to its height and length. Plateaus have an approximately flat surface, which may be greatly cut up by river and atmospheric agents and is then said to be "dissected." In minor details the surface is far from flat and, generally speaking, plateaus and high plains have rougher surfaces than do the low-lying plains.

The earth's surface is subject to slow and ceaseless changes; but changes do not attract the attention of most people, because the span of human life is so short in comparison with the periods of time involved, that the changes escape notice, save when some hurricane, great earthquake, or tremendous volcanic outburst has produced changes in a familiar landscape which compel the attention of the most careless and unobservant. The eruption of Mont Pelée, in Martinique, and La Soufrière, in St. Vincent, in 1902 attracted the interest of the whole civilized world, not only because of the great loss of human life and destruction of property, but also because of the great alterations wrought in those islands. However, such catastrophes do not bring about the most important and significant changes;

they are, comparatively speaking, exceptional. It is the operation of the unnoticed agents that, in the long run, counts for the most, because that operation never ceases and no part of the land surface is out of its reach. A work that is universal and unceasing must eventually produce stupendous changes, provided sufficient time be allowed. The hundreds or thousands of millions of years in which physicists are now inclined to reckon the age of the earth, afford ample time for the many geographical revolutions through which the earth has passed. The term revolution must not be taken to imply sudden and violent changes, but refers rather to the amount and degree of change.

An attentive examination reveals the fact that the changes through which the earth has passed group themselves naturally into cycles, which are indefinitely repeated, and these cycles are both geographical and geological. There is no reason to think that within the period of recorded human history there have been changes of topography or in the distribution of land and sea to an extent which makes it necessary to take them into consideration. But changes of climate apparently have taken place within that time. Pumpelly, Huntington, and others have brought forward very strong evidence to prove that most important climatic changes, which have had the profoundest effect upon the course of human history, have taken place within the last 4,000 or 5,000 years. If we carry our investigations back to the prehistoric period, to a time when men had already established themselves in Europe and perhaps also in America (though the American question is still under debate), we find that stupendous changes, both climatic and geographical, have taken place since the appearance of man. To mention only one of the geographical differences from that early time in the history of man, North America was united to Asia by a land which occupied the site of the shallow Bering Sea. Great sheets of ice covered vast areas in North America and Europe; and when these continental glaciers had melted away, the minor topography and drainage of the glaciated regions were completely revolutionized by the drift brought down by the ice.

We shall see later that in a geographical cycle the topography and drainage of a given area go through a course of development with definite stages, which are called youth, maturity, and old age. It is not possible to observe these stages in succession in the same region, but we find each of them exemplified in various parts of the modern world, so that an intelligent comprehension of existing topographies requires some knowledge of the manner in which the features of the land are produced, modified, and finally swept away. The process is often called "land-sculpture," because of the analogy of carving a block of stone into relief. The separation of Great Britain from the continent occurred within the human (though not the historic) period. No geographical event has so profoundly affected the course of modern history all over the world as the conversion of Great Britain into an island.

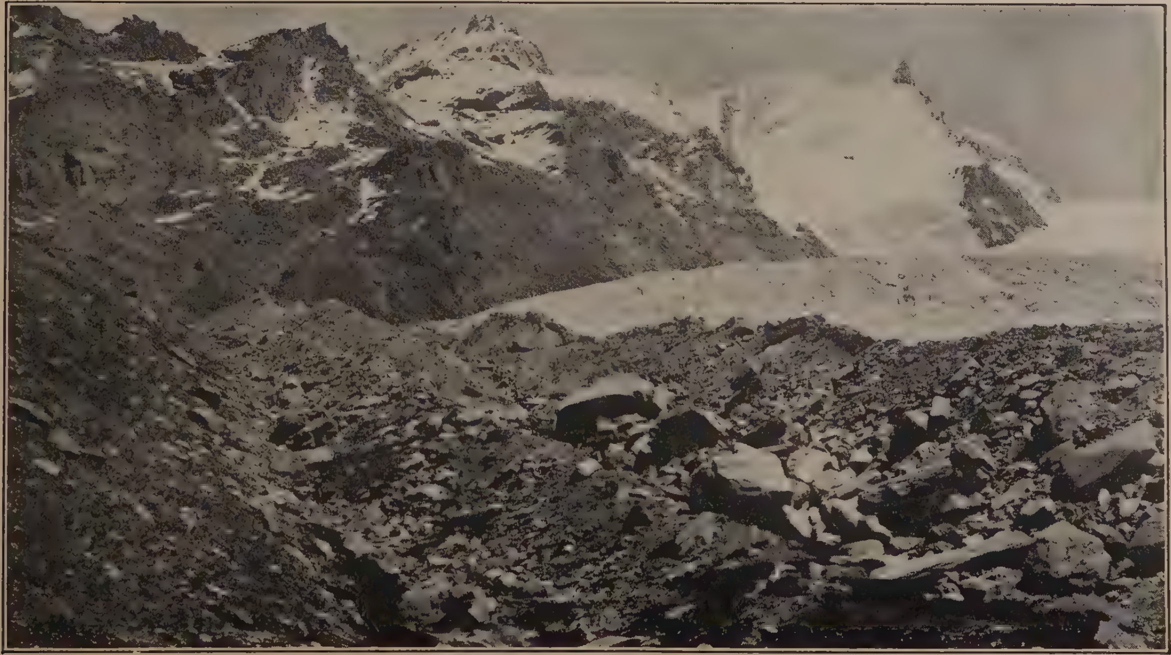
Reviewing the course of human history in the light of geographical knowledge, we observe that always and everywhere man has been controlled and limited by his geographical environment and, unless he were able to leave the earth and betake himself to some other planet, no other relation to the environment is conceivable. Because we have learned how to raise tropical fruit in hothouses, we are not thereby emancipated from the effects of climate. We do find, however, that with the advance of civilization and the perfecting of mechanical devices, the influence and importance of certain geographical factors have been greatly changed. Until the time when railroad building on a great scale was undertaken, the rivers of North America were of the utmost importance to the European settlers. It was by means of the water courses that the French fur traders and missionaries so rapidly explored the continent. The agricultural and commercial development of the Mississippi valley was due to the rivers and especially the river steamboat. The abundant water power was one of the factors which made New England the manufacturing section of the Union. The coming of the railroad completely changed all this and, by greatly cheapening coal, reduced the importance of water power. Now, of late, the development of hydroelectric machinery has restored the importance of water power, and river traffic will revive with great increase in the cost of coal. This is but one illustration of the manner in which the influence of geographical factors may change with the development of civilization.

The agents of geographical change which will be considered in succeeding chapters are manifestations of energy, and we may conclude this chapter with an enumeration of the sources of that energy.

The first of these sources is the interior heat of the earth itself, which is displayed in volcanoes, hot springs, earthquakes, and in the slow rising and falling of the land surface with reference to the sea level. Sedimentary rocks were formed originally in horizontal layers, but now they occur in all sorts of attitudes, gently or steeply inclined, thrown into great curves or folds, or elevated to great heights while keeping their horizontal position. Or they may be fractured and dislocated, the rocks on one side of a line of fracture being pushed up or dropped down. These *earth movements* are in progress now and may frequently be observed; sometimes the movements are sudden and violent, sometimes exceedingly slow; in either case they are very effective agents of topographic changes.

The rotation of the earth has certain important results in modifying movements that have been initiated by other agencies, though it can hardly be called a source of energy. Moving objects are deflected by the earth's rotation and, for example, the trade winds on a stationary earth would blow directly toward the equator in both hemispheres, but on the revolving earth they are deflected so as to become northeast and southeast winds; currents of water are similarly affected.

Another class of agents is that which is derived from the energy which the earth receives from the sun. The rain, wind, frost, running water, ice, and sea waves belong in this class, and would immediately cease were the earth cut off from the influence of the sun. The attraction of the sun is one factor in producing the tides, but these are principally due to the attraction of the moon.



LATERAL MORAINES ON THE NORTH SIDE OF FINDELEN GLACIER, NEAR ZERMATT, SWITZERLAND

GORNER GLACIER, LOOKING TOWARD THE BREITHORN

CHAPTER II

AGENTS OF GEOGRAPHICAL CHANGE

TWO sets of processes are unceasingly at work upon and within the earth, and the modern condition of the earth's surface is due to their long-continued interaction; sometimes they operate so as to increase one another's efficiency, sometimes they oppose and counteract one another. These processes are the subterranean forces, especially movements of the earth's crust, on the one hand, and the surface agents of the atmosphere, running water, etc., which have their origin in solar radiation, on the other. Nothing is clearer than the fact of constant and unceasing geographical change throughout the earth's long history, and shifting of the boundaries of land and sea has been going on for ages past. This shifting is now in progress and may occur suddenly in association with earthquakes, or with almost imperceptible slowness. The regions of ancient civilization, like the Mediterranean lands, notably Egypt, Greece, and Italy, show the clearest evidence of these changes within historic time. The island of Crete has, as it were, rotated upon a north and south axis, so that the eastern end has gone down and the western end risen. The changes of level in Scandinavia attracted the attention of the Swedish Government more than a century ago, and they fixed bronze plates with tide marks on the rocks of the coast to register future movements.

These have not failed to occur and the Scandinavian peninsula is found to be slowly rising; the maximum movement is at the North Cape, where it is estimated at 9 feet per century. In association with the earthquake of 1899, stretches of the Alaskan coast rose as much as 47 feet, and for months afterward dead seaweed and barnacles might be observed clinging to the rocks many feet above high tide. Movements of this description consist in actual rising or sinking of the land, and though sometimes extensive, are yet local in their effects; and sections of the coast that are in close juxtaposition may be moving in opposite directions. There is no reason to suppose that similar crustal movements may not also take place in the bed of the sea. An extensive depression of the ocean floor would lower the sea level and make it appear that the coasts had risen; conversely, a widespread and considerable elevation of the bottom would raise the sea level and produce an apparent sinking of the lands. Such changes could not be local, but would affect all coasts in the same sense, raising or lowering the sea level everywhere.

The earth movements of elevation and depression would appear not to be constant and continuous, but more or less spasmodic; nor are they rhythmical, returning after approximately equal periods. The geographical cycle is from low-lying, featureless land back to low-lying, featureless land, the steps being elevation, wearing down, reelevation, renewed wearing down, and so on indefinitely. It is because these earth movements are not equally separated in time, and not always equal in amount, that the cycles are sometimes complete and again incomplete. Reelevation may occur before the wearing-down process had been completed, thus starting a new cycle before the old one had been finished. The denuding agents do not operate like a plane on a board, stripping away the whole surface simultaneously and lowering it everywhere to the same amount. They work along lines of maximum rapidity of operation, which are chiefly the river channels; though the whole surface is everywhere subject to attack, between the streams this attack is incomparably slower. As the region grows old, the river valleys thus formed grow continually wider and the divides, or watersheds, between them become narrower and lower until, if the cycle is allowed to be completed, irregularities are worn away and an approximate plain, everywhere nearly or quite at base level, is the final result, whatever the starting point of the cycle may have been.

The crustal movements of the earth are of two principal kinds. There is, first, the simple movement of uplift or depression, whether or not accompanied by fracturing and dislocation of the rocks. The rocks affected by the movement retain their original horizontality of bedding, or are tilted in one or the other direction. The uplift movement is only seemingly such, as a rule, like the apparent flatness of the earth; far more commonly it is an upward or downward warping of the surface, so gentle that the curvature becomes apparent only when a large area can be seen at once. A typical instance of this is afforded by the Scandinavian peninsula, already referred to; a careful survey shows that the movement now in progress there is an upwarp, with the line of maximum movement in the mountains along the frontier between Norway and Sweden, diminishing in amount away from this line. When a map of the whole area affected, with contour lines connecting the points of equal elevation, is examined, it is seen that a very flat, domelike elevation has been produced.

The second kind of earth movement is that which is especially exemplified in mountain ranges. The sedimentary rocks, of which nearly all mountain ranges are composed, were originally formed in a nearly horizontal position, this horizontality being a necessary result of the manner in which gravity operates. Just as a deep fall of snow buries the inequalities of the ground and makes an even, flat surface, so sediments, thrown down on the floor of a lake or of the sea, form horizontal beds. Material settling through water or quiet air does so in flat, horizontal layers. Earth movements of the second class are compressive, and in consequence of this compression the horizontal strata are crumpled into undulating folds. The degree and intensity of crumpling varies greatly in different places. In the Jura Mountains of northern Switzerland, and the Appalachians, the folds are comparatively gentle, while in the Alps compression has been very violent and the folding intense.

Areas of warping have, as a rule, no particular shape or dimensions, and one diameter does not very greatly exceed another; but areas of folding are usually long, narrow belts, as in the Appalachians, for example, which are more than 700 miles long in a direct line and seldom more than 50 or 60 miles wide. Westward, the folded strata of the mountains become the slightly tilted beds of the plateau, which descend gently into the plains of the Mississippi. Eastward, the Appalachian rocks do not extend, but are replaced by beds of a different geological date and different mode of origin.

Areas of upwarp are frequently traversed by *faults,* an old miners' term, which geologists found ready-made for them and were glad to adopt. In a fault there is a linear fissure or crack, which may be prolonged for many hundreds of miles, or may be only a few feet in length. On one side of this fissure the rocks have been pushed up or settled down, or both movements may have occurred simultaneously, one side rising (upthrow side) and the other sinking (downthrow side). The amount of displacement, measured vertically, may be anything from a fraction of an inch to many thousands of feet. A moment's consideration will show what great importance faults have for the miner; if he is following an economically valuable bed, like a coal seam, or a vein of ore, it suddenly ends and runs against a rock of totally different character. The fault plane, which may be smooth and clean-cut, or a zone of shattered rock, smashed by the rock's moving in opposite directions, tells him what has occurred, and the problem of locating the vanished bed or vein may be of very great consequence. Has it gone up or down? and how much? After it has been found, will it be practicable to work it? or must the mine be abandoned? It is hardly to be wondered at that, long before there was any science of geology, miners had learned much concerning the behavior of faulted rocks.

The fault plane is rarely vertical, nearly always steeply inclined, and the amount and direction of this inclination is of great topographical significance. Faults seldom occur singly, but much more commonly in parallel and intersecting series. Thus great areas of the earth's surface are a mosaic of "fault blocks," huge blocks, many miles in extent, which are formed by intersecting faults. Along a great line of fault, where the upthrow side is still standing, there will be a line of cliffs, the height of which will be dependent upon the amount of displacement measured vertically. In the course of time, the cliff, or "fault scarp," as it is called, is attacked and gradually worn away by the destructive agents, until all surface indications of the fault are swept away; but, under certain conditions, the scarp may persist for a long time, even from the geological point of view.

The result of warping upward is to produce areas—it may be very large ones—of gentle curvature or slope, which may be low plains, or, when raised to great height, form lofty plateaus. The warped area may remain entire, or it may crack into a system of fault blocks, which, settling to different levels, mark out the country in intersecting or parallel lines of cliff. The result of folding is to produce parallel ridges, separated by intervening valleys, so that these various kinds of earth movements not only produce very different geographical results, but they must be differently affected by the attack of the destructive agents until, in the last stages of a cycle, relief of land surface, however produced, is worn away and only the low-lying plain remains.

These earth movements may still, in part, be observed, as was described in the foregoing paragraphs. Folding has not been observed on any large scale, partly because of the extreme slowness with which the work is accomplished, and partly because the operation is a deep-seated one, not visible from the surface. Warping has actually been observed in the case of Scandinavia and, most frequently of all, faulting has been noted as an accompaniment of violent earthquakes. In Iceland, Alaska, Japan, California, South America, and many other places, including the bed of the sea, faults have been seen immediately after their formation. The greatest displacement yet recorded on any one occasion on the land is one of 75 feet in Iceland.

The surface agents, rain, rivers, frost, etc., are engaged in carving or sculpturing the surface, disintegrating and removing the rocks, producing ridges, valleys, hills, and dales by eroding material along certain lines. The relation of these eroding or denuding agents to the movements of the earth's crust is an important one. In one sense, they work against one another, the earth movements producing and increasing irregularities of the surface, the denuding agents first increasing and then removing the features of relief. Had there been no earth movements after the first production of the continental platforms and ocean basins, the land would long ago have been reduced to a flat, featureless plain, but little above sea level, or altogether removed by the cutting action of the sea. On the other hand, elevation of the land increases the activity of the denuding agents, especially of running water.

The cutting and transporting power of a stream is dependent upon the velocity of its current, and velocity depends upon the slope of the bed and the volume of water. The power that gives the stream its power to trench its bed and carry away its load of gravel, sand, or mud, is gravity. Rivers, even those that flow over hard rocks, cut down their channels with relative rapidity, but at a diminishing rate; for as the channel is lowered, the fall, and with it the velocity of the current, is decreased. When the fall is no longer sufficient to cause any deepening of the channel, the stream is said to be base-leveled, or to have reached its base level. If a region in which all the streams have reached base level be reelevated, the streams are rejuvenated and begin again to cut downward with renewed efficiency. If, on the contrary, a region in which the streams are still active is lowered or depressed, the fall of the streams and their velocity will be correspondingly reduced, while their lower valleys are invaded by the sea and "drowned." The large rivers of eastern North America are not at present deepening their beds because of the comparatively recent depression of the coast and invasion of the valleys by the sea. The diminished fall has removed their power to cut downward. Chesapeake Bay is the drowned lower valley of the Susquehanna; the Delaware and the Hudson have been converted into estuaries.

The highly important work of atmospheric disintegration of rock, or "weathering," is also much affected by altitude above sea level. Rock destruction and shattering reach their maximum rapidity and efficiency in high mountains, where rock waste is far more conspicuous than in low-lying plains. The elevation of a mountain region, therefore, causes the rejuvenation and increased activity of the atmospheric destructive agents. It is this relation between the subterranean and the surface agents which has brought about the cyclical repetition already referred to, and the geographical side of which must be further dealt with.

The important thing to emphasize at this point is that the land surface is being slowly but inexorably worn away and in a manner that can be measured, or at least quite closely estimated. According to De Lapparent's calculation, about 20 cubic kilometers of rock material are annually removed from the land and deposited in the sea, a quantity which would be largely increased were the continents raised considerably above their present level, or were new mountain ranges formed, or old ones increased greatly in height. No doubt, the more exact knowledge to be gained in the future will considerably modify De Lapparent's estimate, but this represents, at least, the order of magnitude of these operations.

Still another cause of topographical variety is to be found in differences of climate. The activities of rock destruction and removal go on most rapidly and effectively in regions of heavy rainfall and great annual range of temperature. Rain that is precipitated in very frequent gentle showers, as usually happens in Great Britain and Ireland, is less effective than the same amount of water falling in fewer, but much heavier downpours. The torrential violence of a so-called cloud-burst often accomplishes a surprising amount of destruction in a very short time. In arid regions the rain and frost do relatively little work, and rock destruction is almost entirely mechanical and carried on by the wind, and by the heating of the rocks by a desert sun followed by a swift chill that comes after sunset. As a result of this difference in the effective agents of destruction, the topographic forms in arid regions are entirely different from those in regions of normal rainfall; and "desert topography," or "arid topography," is a term that may properly be used. In a subordinate degree, this difference is further accentuated by the vegetation, which in rainy regions forms a dense covering of forest growth or of a luxuriant growth of grass. This dense covering is a great protection against the mechanical wash of rain, though assisting in the work of chemical decomposition. Removal of the forest has, in areas of steep slope, resulted in washing away the soil and ruining the land for agricultural use. In arid regions the covering of plant growth is much more scanty and may disappear altogether, as in the true deserts. The comparatively rare rains are able to accomplish much destructive work, because soil and rock are exposed naked to their attack. Arizona and New Mexico and the drier parts of Colorado, Utah, Nevada, and southern California, all have a totally different aspect from the regions east of the Missouri River, a difference which is emphasized, but not caused, by the contrast in vegetation. It is a difference in the shape and arrangement of the hills, in the form of the valleys, in the sculpturing of the soil slopes, and is so pronounced that the traveler cannot fail to observe it. It is the effect of different climates upon the process of land sculpture.

In regions of normal rainfall also we find a great variety of topographic forms in accordance with the destructive agent which has been most active in a given district. In the tropics, for instance, there is no work accomplished by frost save in very high mountains above the limit of forest growth. In the polar regions no work is accomplished by rain, because there all precipitation is in the form of snow. The glacier, or flowing ice, produces extremely characteristic topographic forms, and though at present glaciers are limited to the polar regions and to very high mountains elsewhere, at a time geologically recent continental ice sheets covered vast areas of Europe and North America, and these gigantic glaciers remodeled the topography in a manner that could have been accomplished by no other agent. The contrast between the glaciated and nonglaciated parts of the continent is extremely striking.

There is still another, but quite passive, factor in producing the infinite variety of land forms, which like the active factors previously mentioned is variable. This passive factor is given by the character and arrangement of the rocks in the region to be studied. We have the different sorts of movements of the earth's crust, warping, faulting, or folding, the preponderance of this or that agent of destruction, each of which does its work in its own characteristic way and produces characteristic results; and the character and arrangement, or alternation, of the rocks, introduce another set of variables to add to the endless variety of forms seen on the land. Masses of rock which are of very great thickness and of uniform character will manifestly give a different result, when carved by the denuding agents, from the forms taken by a series of beds which frequently change from hard to soft. Thus, a different topography will arise, even though all other factors be similar. As will be seen in a later chapter, the system of streams that is developed in any region is conditioned by the arrangement and slope of the rocks which form the surface at the time when those streams first began their flow and, in turn, the streams largely determine the relief and sculpture of the land.

Each of the three main classes of rocks, igneous, sedimentary, and metamorphic, has its own characteristic way of reacting to the assault of the denuding agents, so that the experienced geographer, when traveling through an unfamiliar region by railway, can form a very shrewd estimate of the character of its rocks by observing the topographical forms which those rocks have assumed. Unending as is topographical variety, the forms may still be grouped into natural classes, which immediately proclaim themselves to the trained observer. One such class is the climatic, spoken of above. Another is determined by the principal agent which produced the result; the unmistakable landscape of the glaciated region is an instance of this. Still another class is that in which the predominant factor is the nature and arrangement of the rock masses, just referred to. Again, we have the class in which earth movements have been the principal factor; and still another class is given by the stage of development within the geographical cycle which a given landscape has reached.

THE SEA

As an agent of rock destruction, the work of the sea is confined to the coast, which is to be thought of as a belt, not a line. The destructive action of the sea is accomplished principally by the wind-driven waves and breakers, and the area subject to their attack is much broadened by the rise and fall of the tide. Tidal currents act like a reversible river, flowing sometimes with great velocity in one direction during flood-tide and in the opposite direction at ebb. The tidal currents scour out the bottom to depths which cannot be reached by the breakers, for these do no effective work far below the limits of low tide.

The effect of the sea's attack upon the land differs greatly in accordance with the character of the coast. Low-lying, flat, and sandy coasts, like that of the eastern United States south of New England, may be rapidly cut into and carried away by the action of waves and currents, but the effect is to produce simple forms, with very little irregularity or indentation of the coast line. Such coasts, however, are usually areas of accumulation, where the land has been built out into the sea; but they sometimes suffer severely from heavy storms, as the shore of New Jersey has done, especially in the neighborhood of Long Branch. The surf, which on steep and rocky coasts never ceases its destructive work, is ordinarily ineffective on a flat coast; but long-continued and violent winds, which pile up the water and drive it over the land, cause great destruction sometimes. The Zuider Zee in Holland is an example of this. In Roman times about three-fourths of its area was land, the extent of which is marked by the curved line of five islands at its outer margin. The arm of the Rhine called the Yssel flowed across this land and through a lake which occupied the site of the southernmost part of the Zuider Zee. The Yssel is believed to have entered the North Sea between the present islands Vlieland and Terschelling, which were then part of the mainland. The work of destruction began in the fourth century A.D., and was carried on by exceptionally severe northwesterly gales which drove the sea far in over the low-lying land. The years 1170, 1237, and 1395 are particularly recorded as times of great loss. It is estimated that since the time of Julius Cæsar the sea has swallowed up 5,813 square kilometers of land, of which only 3,635 have been regained by diking. A great project is now under way to build a huge dike across the narrowest part of the sea and pump it out, maintaining the sea connections of Amsterdam by means of a ship canal. The Frisian Islands on the North Sea coast of Germany have been very greatly reduced in size between 100 and 1854 A.D.

A high, rocky coast, where the cliffs rise abruptly from the sea, like the shore of Maine, Great Britain, northwestern France and many other places, is cut back by undermining, the sea excavating the foot of the cliffs, the face of which falls when it can no longer support its own weight. As the rock masses are of unequal hardness, the softer parts are removed first, leaving the harder to stand out in relief; and therefore such a coast becomes much more irregular than one which is made up of loose materials. However, such irregularity is but a passing phase in the development of the coast line.

The result of the sea's cutting is to form a platform, covered with shoal water, or perhaps bare at low tide. As the width of this platform is increased, the effectiveness of the sea's action is retarded, because of the shallowness of the water on the platform and the consequent friction which the waves must overcome before they can attack the foot of the cliffs. So long as the sea level remains constant, this submarine platform will broaden slowly, but on a gradually sinking coast the cutting is more rapid. An example of a wave-cut plain is found on the north coast of Spain, on the Bay of Biscay side, where there is a broad platform between the mountains and the sea, which is almost perfectly flat and of comparatively recent elevation. On the west coasts of Scotland, Ireland and France, platforms, still in the course of extension, occur as shoals and reefs dangerous to navigation. The west coast of Norway and part of the east coast of India are bordered by sea-cut plains, thirty to sixty miles wide. When a steep coast is made up of soft materials, like part of the Yorkshire coast on the North Sea shore of England, the surf works with maximum efficiency; that coast is retreating at the rate of seven to ten feet a year and has lost three miles since Roman times.

It must not be assumed that all, or even most, plains have been produced by the cutting back of coasts by the waves. Plains are formed in other ways, as will be shown in subsequent sections.

SUBAËRIAL AGENTS

The other agents of rock destruction are grouped together under the term "subaërial," because they operate on the surface of the land and are, in a sense, independent of the sea, though, of course, the sea is the source of rain. The subaërial agents are acting upon the entire land surface of the globe and their attack is unceasing. Different agents predominate in different regions, in accordance with the climate and also the altitude of the region. If we imagine these agents attacking a new land, which is at considerable height above sea level, so as to give velocity to its streams, we shall find that the first effect of these agents is to increase the irregularity of the land surface, or to produce irregularity, if that surface was originally plane.

Such irregularity, thus produced, is but one stage in the topographical development of the area in question. After diversity of relief has reached its maximum, it begins to diminish and finally, unless the process be interrupted by an elevation of the land, the region will be cut down to a low-lying plain, but little above sea level and with hardly any diversity of surface. Such a plain may persist for ages almost unchanged, because its streams are so sluggish for want of fall that they cannot remove the débris made by atmospheric decomposition of the rocks, and that decomposition ceases when the soil has become sufficiently thick. This is the geographical cycle, already referred to, and geographers distinguish the stage of youth, maturity, and old age, terms which are applicable to all sorts of geographical features which are subject to change, to mountain ranges, sea coasts and river systems, as well as to land surfaces in general.

A youthful topography is one in which the rivers flow in gorges and cañons, rather than in ordinary valleys; the drainage system is but partially developed; and the divides between the streams are broad, flat-topped areas, while the streams are obstructed by many falls and rapids. A topography which, though youthful, owed its character to folding, like the Jura Mountains, would be described in somewhat different terms. The length of time during which the youthful stage persists will depend upon the climatic conditions, on the one hand, and the resistance of the rocks, on the other.

The period of maturity is that in which there is a maximum relief, the greatest possible diversity of surface in hill and valley, ridge and plain; in which the drainage system has been fully developed, so that all parts of the surface are reached by it; and the valleys have been opened out into broad troughs, with gently sloping sides, retaining the gorgelike character only where the river has cut through exceptionally hard rocks. Rapids and waterfalls have been generally cut down, except near the headwaters of the streams, and the divides have been reduced to narrow ridges. The duration of this stage also varies with climate and rock resistance; it persists longest in a region of dry climate and very hard rocks, least in a country of heavy rainfall, severe winters, and soft, easily destructible rocks.

A continuation of these processes brings on old age, in which the topography is almost without diversity. This stage may persist indefinitely, because changes have become excessively slow. Only by a reelevation of the land, which closes the cycle and inaugurates a new one, can the condition of old age be ended

RIVERS

Rivers cut channels with vertical sides and continue to cut and deepen them until base level is reached. When a stream is at base level, its profile from source to mouth, with all meanders and irregularities removed, is a parabolic curve, rising quite steeply in the headwaters toward the source. The profile of the Loire in France coincides almost exactly with the theoretical curve of a base-leveled stream. Rivers also undermine their banks, as the current swings from side to side and impinges now on one point, now on another. so that a stream often cuts a channel considerably wider than itself. Unassisted river action produces the vertical-sided gorge, the possible depth of which is limited by the altitude above sea level. The Grand Cañon of the Colorado, and a great many other Western cañons, are trenches many thousands of feet deep; in central New York the vertical-sided gorges are only a few tens of feet in depth. This great difference is in part due to difference in altitude, which is but moderate in New York, and in part to difference in age, the New York cañons being very young, far younger than those in the arid West.

The trenchlike gorge with vertical sides is not, however, the usual or typical river valley, because the atmospheric agents, rain and frost, and especially the undermining action of springs and ground water, are constantly wearing away the sides of the gorge, producing land slips and rock slides. As the top of the trench is the part which the river first cuts and which has been longest exposed to weathering, it is naturally the widest part, and so the valley takes a V-shape in cross-section. The destructive attack upon the sides of the gorge is made under unusually favorable circumstances, because the débris is carried away by the river and does not remain to bury the rock and retard the work of disintegration. Old river valleys in moist climates are wide and have gently sloping sides, save where the rock structure favors the retention of the vertical form. Usually, this is due to the river's crossing a band of exceptionally hard and resistant rock, as, for example, is true of the Delaware Water Gap, a narrow gorge cut through the steeply inclined and very hard rocks which form the Kittatinny ridge. Above and below the Gap, where the river flows over much softer rocks, the valley is broad and has very gently sloping sides, save where harder rocks come to the surface as ridges, like Wallpack Ridge above the Water Gap. All the larger streams that flow across the mountains, the Lehigh, the Susquehanna, and the Potomac, to mention only three, have their narrow gorges or "gaps" in the local parlance, and always these are in the bands of hardest rock; elsewhere the valleys are broad.

Another manner in which a valley may long retain vertical or, at least, very steep sides, is when those sides are composed of hard and very soft rock in alternating beds; the recession of the walls is then carried on chiefly by undermining, the soft beds being easily removed, the hard ones are undermined and, when unable longer to support its own weight, the rock falls, leaving a vertical-faced cliff, the height of which is determined by the thickness of the hard bed. The softer beds form gentler slopes, and so the profile of the valley wall is formed by a succession of sloping and vertical faces. The Niagara gorge has retained its precipitous sides, partly because of its youthfulness, and partly because of the mass of hard limestone which forms the top of the wall, beneath which is a thick body of soft shale, and thus retreat is by undermining.

The rapidity with which the narrow, vertical-sided trench, made by the river without assistance, is widened into the V-shape and then into the broad open valley, varies greatly in different regions and depends upon two classes of factors, and, first, upon the climate. Narrow, steep-sided gorges, or cañons, are very much more frequent in arid climates, because in them the atmospheric attack usually works with minimum effectiveness. The second factor is the resistance of the rocks which has to be overcome. Even in a climate of heavy rainfall and violent frost, a trench in very hard and resistant rock will be broadened much more slowly than one in which the rocks are soft. In old rivers, such as the Delaware and the Potomac, the gorges are invariably in hard rock. The gorges in central New York are vertical-sided, in spite of the softness of their rocks, but that is accounted for by the fact that the streams which made the gorges are themselves very youthful, and notwithstanding the softness of the rocks and the character of the climate, there has not been time to cut back the walls. As will be shown in a later chapter, the great continental ice sheet of the Glacial Epoch left behind it a thick mantle of drift which filled up the minor valleys and obliterated all but the larger streams. Hence, in the glaciated region, of which central New York is a part, the smaller streams were established after the withdrawal of the ice. Thus, the same effect is produced by youthfulness in one climate and by aridity in another.

Rivers also produce changes in topography, by the deposition of part of the load of sediment which they are carrying, for they are the most active and efficient of all agents of transportation and the amount of material which they transport is entirely dependent upon the velocity of the current. When a stream is traced from a mountain source to the sea, the character of the material in its channel changes, growing finer toward the mouth. The mountain torrent sweeps along everything but the large bowlders; farther down the stream the smaller bowlders lie in the stream bed and are moved only in times of flood. Then in succession follow cobblestones, coarse and fine gravel, coarse and fine sand, and finally mud. For many hundreds of miles above its mouth, the Mississippi transports only fine mud. That part of the river valley which is annually overflowed is called the flood plain. Egypt is, of course, the best known and most familiar instance of a regular annual overflow, which by depositing a thin layer of mud every year has built up a country of proverbial fertility upon a foundation of desert sand. At the mouths of many rivers, whether in lakes or in the sea, the deposition of river-borne detritus has built a delta. The delta of the Mississippi is over 12,300 square miles in extent and advances into the Gulf of Mexico at the rate of one mile in 16 years; the delta of the Ganges and Brahmaputra rivers in India has an area of 20,000 square miles. The head of the Adriatic Sea is fringed with an almost continuous line of deltas which have built out the coast line many miles since Roman times. In the age of Augustus, Ravenna was a naval station, but now it is 11 miles inland. The process has been artificially hastened by the building of levees along the Po and other rivers, which have prevented their overflowing their flood plains and forced them to carry their load to the sea. Port Valais is an ancient Roman settlement, built where the upper Rhone discharges into Lake Geneva, but now it is 1½ miles from the shore. These are but a few of the many examples of land which the agency of rivers has built out into the sea or a lake within historic times.

From the geographical point of view, the most important work of the river is the excavation of valleys and the carrying away of the rock waste produced not only by the river's own activity, but also by all the other destructive agents at work in the region, notably rain and frost. Away from the streams, the wear of the surface is very much slower, because the debris of rock destruction is not quickly carried away and accumulates as thick soil, especially in the valley bottoms where no stream is flowing; this thick soil protects the rock from further destruction. In the slow process of wearing away the land, those parts remain standing longest above the general level which are composed of the hardest rocks and are farthest removed from the drainage lines.

GLACIERS

A second and highly characteristic subaërial agent is the glacier, or flowing mass of ice. Under existing conditions glaciers are rather rare, and the great majority of people in civilized lands have to travel long distances to see one. They are found where the winter snowfall is in excess of the summer melting and where the conformation of the ground permits the accumulation of great masses of snow. They are rare in the tropics, because of the uniformity of the temperature which hampers the necessary process of thawing and freezing; yet glaciers do occur in the Andes of Ecuador, and Mount Kenya, in East Africa, which actually stands on the equator, has quite extensive glaciers. The Rocky Mountains of Colorado and the Sierra Nevada have only a few insignificant remains of glaciers; yet it is plain that these mountains were once heavily glaciated, when almost every valley had its stream of ice. The absence of glaciers now is due to the dry climate, the snowfall being insufficient to support them; but in the Canadian Rockies, and still more in Alaska, are vast glaciers. The glaciers of the Alps are universally known, the far larger ones of Norway are less famous. All high mountains in a sufficiently moist climate carry glaciers, and in both hemispheres the glaciers grow larger and descend nearer to the sea level, the higher the latitude. Greenland and the Antarctic continent are buried under thousands of feet of moving ice; and these ice caps are of particular interest, because they give us the best likeness which is now to be had of the great ice sheets which once covered the northern portions of Europe and North America.

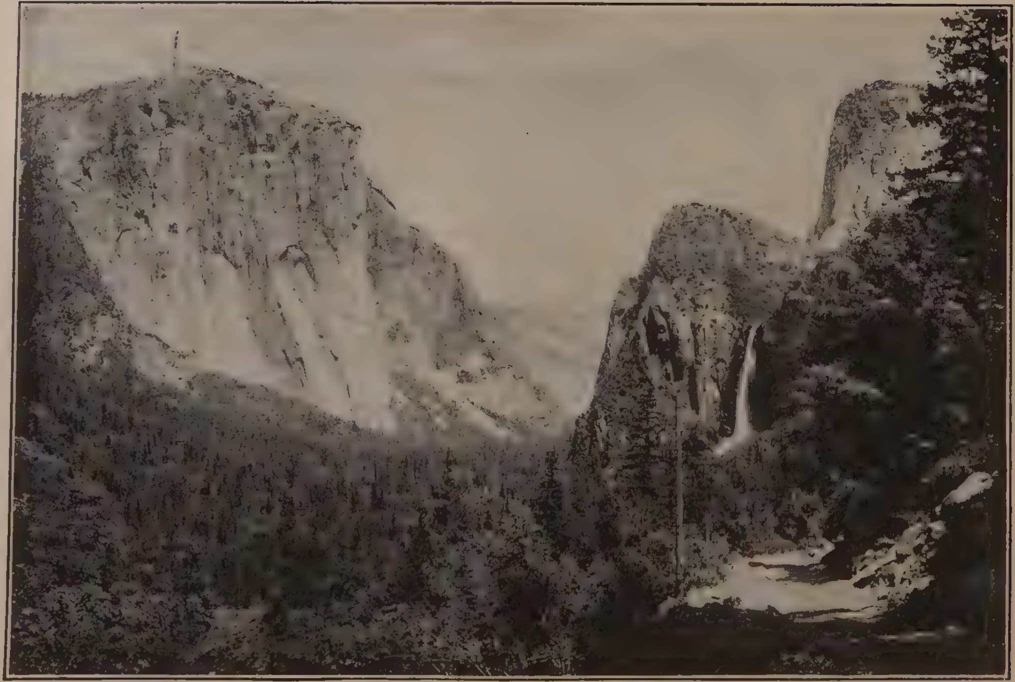
The work which is accomplished by glaciers is still a matter of dispute, some geographers attributing very much more importance to glacial erosion than do others. Into the merits of this controversy it is not necessary to enter, nor even to explain why there should be any controversy. It seems strange that observers should differ so radically concerning the work of agencies which are in actual operation to-day. It must suffice to say that, were it easy to determine just what modern glaciers are doing, there would be no difference of opinion about it.

There is, however, and can be, no difference of opinion concerning the characteristic features of a glaciated region, because not only are they too plain to admit of doubt, but because they are repeated invariably in all glaciated regions. Certain features of glacial action are imitated by other agents; and in a region which has unquestionably been glaciated there may be doubt as to just how much rock material the ice has removed and how large a share should be attributed to the water which is always found beneath the ice and at its melting margins. The topography of a glaciated region is marked by rounded and flowing contours of hill and rock; cragginess and angularity are conspicuously absent. Comparing the surface features of New England and New York with those, say, of Kentucky or Tennessee, the difference between glaciated and nonglaciated areas is made clear, even though we cannot always determine precisely what the ice accomplished.

In the region where the ice was thickest and moved most rapidly, glacial erosion was most active, sweeping away all loose material and soil and leaving bare and solid rock, as in the region of Canada north of Lake Superior. The solid rock over which the glacier flowed, called the "ice pavement," is smoothed and, if sufficiently hard, is highly polished, and in either case is marked by parallel striæ, which range in size from hairlike scratches to deep and wide troughs. These highly characteristic marks, the "glacier's autograph," are caused by the hard fragments, from grains of sand to great bowlders, which are frozen in the bottom of the ice and dragged over the rocky floor. Being held at fixed distances apart, they make parallel markings, as do the teeth of a harrow. Rounded hummocks of rock, smoothed on the side against which the ice impinged and rough on the other side, the "roches moutonnées" of Swiss geologists, are also very significant of glacial action.

Glacial valleys are as characteristic as glacial hills, and their peculiarities can best be made clear by a comparison with river-cut valleys. The latter tend to a V-like cross-section and a winding course; where the valley is through mountains, tributary

A GLACIAL HILL



YOSEMITE VALLEY FROM ARTIST'S POINT. The picture shows the glacial U of the main valley and the U-shaped hanging valley of Bridal Veil Creek, to the right. These features are the results of a combination of joint control, stream erosion and glaciation. The floor of the valley is filled with alluvium, due to the damming by a moraine which crosses it from near the base of El Capitan Cliff, on the left.

valleys come down from each side, separated from one another by spurs, around the projecting ends of which the main valley winds in its sinuous course. The tributary valleys and their streams enter the main valley at grade, i. e. there is no marked difference of level between main and tributary streams at their points of junction. Unless very youthful, in which case every ledge of hard rock which the valley crosses is the site of a waterfall or rapid, a water-made valley tends to continuity of slope; and in mature valleys, the slope from one end to another is smooth and unbroken, though it may be steep.

In all these respects a valley which has long been occupied by a glacier is characteristically different. Its course is much straighter than that of a river and tends to U-shaped cross section, with flat, often broad, bottom and vertical sides; the spurs descending from the sides have had their lower ends sheared off and form triangular faces. The main valley has been over-deepened and cut down below the level which the smaller glaciers of the side valleys could equal; and when the valleys were all cleared of their glaciers, the side valleys all ended at a level far above the floor of the main valley, and so they are called "hanging valleys." When reoccupied by streams, these enter the main valley by waterfalls; and in the Alps, both French and Italian, as well as Swiss, the ends of hanging valleys have acquired great importance as the site of hydroelectric installations. Both truncated spurs and hanging valleys with straight main valley, may be produced by lines of fault, as in Cattaro Bay, of the Dalmatian coast, or by the rapid cutting back of a coast by the sea, as has been observed on the coast of west Africa and on the Black Sea shore, but none the less they are particularly characteristic of the work of flowing ice.

Still another very general feature of glacial valleys is the discontinuity of their slopes, which are broken up by hard ledges and thus convert a smooth ascent into a great staircase, each flat expanse, often with a lake or marsh, separated from the one above it by an abrupt rocky wall. Mountain glaciers head in great amphitheatres, called *cirques* in Switzerland and *corries* in Scotland. Like so many other features of glacial topography, their mode of formation is disputed, but their association with glaciers is plain. They serve as gathering grounds for vast masses of snow, in which the glacier heads. They work back into the mountain mass which contains them, and the same peak may have three or four of them on the different sides; these work back until they are separated only by narrow rocky ridges, making a skeleton of the peak and preparing the way for its eventual complete destruction. Mountains which have been heavily glaciated are noted for the great number of passes which notch the rocky walls between adjoining valleys. These passes are produced in several ways, but in the Alps they are generally attributed to the overfilling of a valley with ice, which flowed over the bounding sidewall at its lowest point, and then cut down through the rocky barrier. The passes in the Appalachian Mountains have usually been made by streams, even the "wind gaps" in which no streams flow at present, and they extend far to the south of the limits of glaciation.

The features of glacial topography so far mentioned are those produced by rock destruction, the removal of quantities of material by glaciers and their cooperating streams. There is another and equally important class of glacial features, caused by the deposition of material, instead of its removal. When water has had no part in making the deposit, it is unstratified, for ice has no power of sorting material as water has, and all its load, whether carried on top of the ice, or frozen within it, or pushed along beneath it, is dropped helter-skelter, when the ice melts, in one promiscuous heap. Thus arises the terminal moraine which skirts the foot of a glacier, and such a moraine has been traced across the whole continent of North America from Nantucket to British Columbia. When the retreating ice sheet halted for some considerable time in its withdrawal, a new terminal moraine was formed and, in Wisconsin particularly, many of these have been mapped. Over the country exposed by the retreating ice was left a sheet of till, or bowlder clay, finely ground material containing bowlders from the size of a child's head to masses weighing hundreds of tons, such as water currents, however swift, would be quite powerless to transport. The stony fields of the New England upland are derived from the till sheet that covers the country and, as they are chiefly of granite, the bowlders are more lasting than the softer rocks forming the bowlders of the till farther to the westward.

In addition to moraines and till sheet, the glaciated region shows many characteristic constructional features, which are due to the water derived from the melting ice, or to the cooperative work of water and ice. Eskers, a term first used in Ireland, are long, embankmentlike ridges of gravel, which often ramify like a drainage system of trunk and branches and are interpreted as the deposits made under the ice in the tunnels of subglacial rivers, such as have been observed in Alaska. Drumlins are not yet satisfactorily explained; though they are known to occur only in glaciated areas. A drumlin (another Irish name) is an oval hill of gravel, sometimes remarkably and beautifully symmetrical, with the long axis in the direction of the ice movement; some drumlins are long and low, two miles in length and 100 feet in height are the dimensions of certain ones; others are almost circular. The drumlins near Boston are notably symmetrical in form; those of central New York, where a very remarkable group of them is found south of Rochester and between that city and Syracuse, are longer, less symmetrical, and more like those described in Ireland, while in Wisconsin they are shorter and more irregular.

If the surface of some familiar glaciated region, like New England or New York, could be restored to the condition it had before the ice advanced over it and then withdrew, the *great* topographical features would be found to be very much as they are now; the plateaus and the mountains, the higher hills and the main river valleys would be found to occupy the places which they still hold, but all the details would be different. Wherever the naked rock is exposed, it now displays the peculiar glacial modeling of rounded, flowing contours, without angularity. Pre-glacial drainage has been largely reconstructed from the records of borings for oil and natural gas, especially in western Pennsylvania and Ohio; and while the large rivers, like the Connecticut, Hudson, and Delaware, have returned to their preglacial valleys, the small streams were obliterated and an entirely new system of minor drainage, with a reversed direction of flow, has been established. One most striking difference from the preglacial landscape is the immense number of lakes which the modern surface possessses. The preglacial area had been land for a very long time, and ancient land surfaces have few lakes, or none at all; even the five great lakes which are drained by the St. Lawrence are post-glacial in date of formation. The general character of the land surface is much smoothed and its minor irregularities buried under the great sheet of till. Over the upland of central New York the till sheet is only three or four feet thick, but in the buried valleys it is often several hundred feet thick, leaving no surface indication of the valley beneath; the effect in smoothing the surface and burying the depressions from sight is like that of a deep fall of snow. Thousands of ridges, hummocks, hills, formed by the lines of moraine, the eskers, the drumlins, have further modified the surface, all of the *minor* features of which are due to the ice or to the water derived from its melting. Could one who had known well the pre-glacial landscape have returned before the European discovery, he would have been greatly puzzled to know what had happened to his familiar country. Long and careful study would inform him that the fundamental structure and major topography were as before, but the appearance of the region would have totally changed. The history of the peoples of western Europe, of Canada, and of the United States has been profoundly affected by the events of the Glacial Epoch and the changes which it wrought in the two continents, and their economic future is still largely dependent upon those events. Reserving for a future chapter a more comprehensive outline of the relation between history and geography, it will suffice, at present, to remember that the five great lakes, now the busiest of the world's inland waterways, much surpassing the Suez Canal in tonnage, owe their existence to the happenings of the Glacial Epoch.

THE ATMOSPHERE

The third group of subaërial agents, whose destructive activity is of the utmost importance in the work of land sculpture and the production of topographic forms, comprises those which are grouped together under the general term "atmospheric," and includes rain, frost, wind, and rapid oscillations of temperature. As we have already seen, the latter two are especially important in arid regions, the former two in regions of heavy precipitation and cold winters. Of all agents of rock destruction, the atmosphere is the most important and the most effective, though usually the least conspicuous. It is but seldom that the atmosphere can show such spectacular effects as the great river cañons, but the hundreds of thousands of square miles of "bad lands" in the semiarid West are a gigantic example of rainwash, acting upon soft rocks which have no protective covering of vegetation. What makes the atmospheric agents preeminent in the work of rock waste is the fact that no part of the land surface is exempt from the atmospheric attack and that its destructive work, though sometimes very slow, as in the desert, is ceaselessly operative. Every part of the dry land is always and everywhere undergoing destruction from the atmosphere.

Of these agents, rain is, in one sense, the most important, because it is the only one which operates chemically, the others being purely mechanical; the rain is both chemical and mechanical in operation. In appearance, nothing can seem more futile than the rain dashing against the face of a cliff; and a vertical rock surface, down which the water rolls, is the most disadvantageous condition for effective work. It is on horizontal surfaces, where the water keeps its contact, especially under a thin layer of soil, that chemical work is most effectively done. Just how this work is accomplished depends upon the character of the rock attacked; sometimes merely the soluble parts of the rock are dissolved and carried away, which causes the insoluble parts to crumble; or, if the minerals making up the rock have a highly complex composition, the water will decompose them, converting, for example, granite into clay. The result of this chemical and mechanical attack upon the rocks is the formation of soil and, certain vegetable loams aside, all soils are formed by the disintegration of rock. As they actually occur, certain soils have been brought for a long distance; the alluvial soil of river valleys, which has been transported and deposited by the action of the stream, is an instance of a traveled soil. Glacial soil is another example, though as a rule glacial soils have not been transported very far; still another and very important instance is the loess of north China, which is a fine dust, brought by the winds from the deserts that lie to the west. By far the greater part of the earth's land surface has neither been glaciated, nor flooded by rivers, nor covered by wind-driven dust; and so the great majority of soils have been formed by the decomposition or disintegration of the underlying rock. The process may be observed in any deep excavation and often a very shallow one, such as a cellar, is sufficient to show the transition from the sound, unaltered rock below upward through rotten rock, which looks sound but crumbles in the hand, into subsoil and finally top soil. In the tropics the soil is generally very deep, 200 feet or more, and it is quite rare to find exposures of rock, which makes geological work difficult. In the temperate latitudes, outside of glaciated regions, the depth of soil generally increases from cooler to warmer areas.

The agricultural possibilities of a given region are thus determined, first by the climate of that region, and secondly, by its soil; and the soil, in turn, is conditioned by the nature of the underlying rock, which is the parent of the soil. The best means of ascertaining the agricultural capabilities of a district which has not long been under cultivation, is by a geological survey.

The most important element in the life of the world, after water, is the soil. The conservation of the soil and the maintenance of its fertility are absolutely essential to the existence of mankind. What part the soil plays, and under what conditions, may be best understood after a few preliminary considerations as to the growth and nutrition of plants. Aside from the food taken from the sea, the soil supplies, directly or indirectly, all human food, directly in the case of vegetable foods, indirectly in the case of animal foods. The substance of a growing plant is made up principally of a solid, carbon, and three gases, oxygen, hydrogen, and nitrogen; of these four elements, as the chemist calls them, the three gases are derived from the soil, the solid, carbon, from the atmosphere. Of course, the water, which is made of two parts of hydrogen and one of oxygen and so has the chemical symbol H_2O, is also derived from the atmosphere, but not by the plant, which can only take it by the roots from the soil. A green plant has the wonderful power of undoing the work of combustion and decomposing carbonic acid gas, (CO_2) of which a minute proportion is always present in the air. The truly marvelous work is accomplished by the sunlight through the agency of the plant and ceases in the dark. The first step in plant nutrition is the formation of starch by combining the carbon derived from the decomposition of carbonic acid gas with water in the proportions of six parts of carbon, ten of hydrogen, and five of oxygen, which gives the formula $C_6H_{10}O_5$, which means that six parts of carbon are combined with five of water and that twelve parts of oxygen are set free into the atmosphere. It was by examining the bubbles of gas given off by a bunch of green leaves, submerged in a jar of water and standing in the sunlight, that Priestley discovered oxygen and so began modern chemistry. Starch has a composition similar to cane sugar, and the transformation of starch into sugar and sugar into starch is frequent in the living plant; woody tissue, or cellulose, also has much the same composition. When a plant is dried and burned, which consists in uniting with oxygen, the products of combustion, besides the vapor of water, are gases and go off into the atmosphere; but a small, incombustible residue, the ash, remains behind. The ash consists of various mineral substances which, though present in minute proportions, are yet essential to the life of the plant and therefore must be continually replenished in the soil in order to maintain the fertility of that soil. Every kind of crop that is taken from the farm carries away with it its due proportion of these indispensable substances. The nitrogen, essential to plant life, cannot be taken by the plants from the atmosphere, of which it forms nearly three-fourths, but must be in the soil in a compound which can be dissolved in water and thus taken in through the roots. This compounded nitrogen is said to be "fixed," as distinguished from the free gaseous nitrogen of the atmosphere and, for agricultural purposes, is chiefly derived from stable manure and the nitrate of soda, or "Chile saltpeter," which is found in the rainless desert of northern Chile. Methods of "fixing" atmospheric nitrogen have long been known, but they have been far too costly for commercial use, and the problem of a future nitrogen supply for a densely populated world is one that weighed heavily on the minds of chemists. Cheap and abundant hydroelectric power has largely solved this problem and promises to do so completely within a short time. Had this not been accomplished, Germany could not have continued the war more than a year, for all high explosives are nitrogen compounds and the blockade effectually excluded Chile saltpeter from German ports. Nitrifying bacteria, especially those which form tubercles on the roots of leguminous plants (i. e. the pea family) are a useful means of enriching the soil with nitrogen in form available for plant food. Hence the enriching effects of crops of clover, alfalfa, and other legumes, when inoculated with proper bacteria and ploughed into the soil.

The second indispensable mineral substance which plants must have is phosphoric acid, especially in the form of a soluble phosphate of lime. Wheat and other cereals require relatively large quantities of this, and every bushel of wheat or rye that is exported forever removes from American soil the essential phosphoric acid. Phosphate rock occurs in large quantities in many parts of the world, especially in North America; but, like all other materials which are mined or quarried, the supply of this mineral is limited and some other source of supply must eventually be found. Potash is a third substance which plants must have and which soils must contain if they are to yield crops, and it is required in many manufacturing processes, such as glass making. As its name indicates, potash was originally derived from leaching wood ashes with water and boiling down the strong lye thus made. Our great-grandfathers derived their whole store of potash from this source and, as wood was the fuel in exclusive use, there was an abundance of ashes available as a fertilizer in the wheat fields. The discovery of vast deposits of potash salts at Stassfurt in Germany gave to that country a monopoly of the potash supply. Most people will remember how greatly we in America were inconvenienced by the cutting off of the German potash during the war, and the extravagant prices which were commanded by the scanty domestic supply from Pacific Coast seaweed, Nebraska saline lakes, and other sources. The restoration of the lost provinces to France breaks the German monopoly, for Alsace contains an abundance of potash salts, the exploitation of which has hitherto been held back in the interest of Stassfurt. Spain also contains similar deposits, which await development. Apparently, for centuries to come, the potash question need cause no anxiety, but, as in the case of phosphoric acid, some self-renewing source of supply must eventually be found, if men are to continue to eat bread, potatoes, and such food. In all such problems the difficulty to be met is concentration; potash and phosphoric acid are not destroyed in consumption, but greatly scattered, so as to occur in but minute quantities in any one place. The Pacific kelp concentrates potash from sea-water, and the excrement of birds is rich in phosphorus; it is by utilizing such sources that a perennial supply may be secured.

Soils are derived, as we have already learned, from the disintegration or decomposition of the rock, and over most of the land surface the soil has been derived from the underlying rock, into which it passes gradually through various stages of decomposition. Except for the humus of partially decomposed vegetable matter, such a soil contains nothing that was not in the parent rock and is said to be *residual.* Nearly all limestones contain a varying proportion of insoluble impurities, chiefly clay, which remain as a residue, when the limestone is removed, and thus form a residual soil. The famous "Blue-grass Region" of Kentucky is confined to the area of a certain limestone; when that rock is replaced by others, the soil, vegetation, and agricultural capabilities are completely changed.

In arid regions there is no distinction between soil and subsoil, and the whole mass is extremely rich in the minerals essential to plant life; when irrigated, such soils are remarkably fertile. This is due to the fact that the soil has not been leached for ages by large quantities of descending water, which carries away some of the soluble material. It is true that soil has a curious power to extract from solution and retain substances which, like potash and phosphoric acid compounds, are essential to plant life, but in countries of heavy rainfall there is some loss. When fields have been exhausted, they can often be restored by deep, subsoil ploughing. The fertility of arid soils is due, not only to the absence or diminution of leaching by the rain, but also to the mode of soil formation in dry climates. Here the rocks are mechanically disintegrated rather than chemically decomposed, and thus retain their whole store of minerals needed by plants. The fine rock flour produced by the grinding of heavy glacial ice over the rocky bed and the dust soils accumulated by the action of the wind, share with volcanic soils, derived from the so-called ash of volcanoes, and the soils of arid lands, the quality of undiminished supplies of mineral plant foods. They are all very fertile and need only water to produce, often in an astonishing way.

Of soils that have been brought from a distance and hence are called "traveled," there are three principal kinds, those that have been transported by glacial ice, by rivers, and by the wind. Glacial soil which is strictly such and has been formed without the cooperation of water, has, as a rule, not traveled very far and, in large part, still lies upon its parent rock. It is true that bowlders which were on the top of the moving ice may be transported for long distances, like the huge masses of New Hampshire granite that are found in Long Island, or the copper-bearing bowlders which were carried from Lake Superior to southern Indiana, but the great mass of glacial soil was pushed forward beneath the sluggish ice near the periphery of the ice sheet, and has seldom been moved very far from its place of origin. A glacial soil is very apt to be a till and full of bowlders which have to be removed before the fields are arable. This has entailed enormous labor and has added greatly to the difficulties of agriculture in New England, largely because the bowlders are chiefly of granite, which is very hard and yields but slowly to the action of the weather. Under such circumstances the New England farmer, in competition with the West, has been severely handicapped and many farms have been abandoned in consequence. In New York and Pennsylvania, the States of the Middle West, and the Canadian Province of Ontario, the glaciated areas have a better soil, because it is derived from sedimentary rocks which have been more completely disintegrated and the fields are less stony.

Alluvial soils, from their mode of formation, are confined to valleys and especially to that part of them which is annually, or at least frequently, overflowed by the river and is hence called the flood plain. Deltas in lakes and in the sea, some of which are very large and have surface areas of many thousands of square miles, are of course alluvial. When the river is allowed to inundate its flood plain and is not confined to its channel by levees, the soil is annually renewed and fertility maintained indefinitely. This is the system followed in the Nile valley, which has been highly cultivated for thousands of years past. In the flood season the whole valley, between the high rocky bluffs on each side, seems like a great lake; the villages are built on artificial mounds which raise them above the water, and all communication between them is by boat. The alluvial soils of the Mississippi Valley, in the strict sense of that term, are famous for their fertility, but then great sums of money and vast effort are expended to confine the river to its channel and keep it from covering the flood plain. Whether it will not, in the future, be found advisable to follow the Egyptian system, rather than let so many million tons of valuable mineral substances pour uselessly into the Gulf of Mexico, is a question which the future must decide. In this instance, however, the problem of the malarial mosquito must be taken into account. All over the world the river valleys are not only the natural lines of communication, by boat, by railway or by the highroad, but they are, to a very large extent, the chief seats of agriculture, because of their deep alluvial soils. Especially is this true of dry regions in which agriculture is entirely dependent upon irrigation and it is impossible to bring water to the uplands. Egypt is, again, the best-known example of such conditions. The traveler, coming from either side, crosses a desert of shifting sands, desolate and without vegetation and suddenly, as he reaches the bluff which marks the edge of the valley, he sees at his feet a narrow strip of verdure, thirty to fifty miles wide and hundreds of miles in length, where a luxuriant vegetation is nourished by the river. The Egyptian priests who told Herodotus that "Egypt was the gift of the Nile," told a truth without exaggeration.

A third class of traveled soil is that which has been accumulated by the wind; in some instances it has been carried for great distances before finally coming to rest, and therefore consists of extremely fine particles. This wind-accumulated soil, which has certain remarkable characteristics that recur wherever the soil is found, has received the German name of *loess*, because it was first clearly identified and named in Germany. It also reappears in the Mississippi Valley and is especially important in Iowa, Missouri, and the Dakotas. In both the German and the American occurrences loess is of ultimately glacial origin; the fine rock flour, produced by glacial grinding, is sorted out by the wind and its finer particles carried for long distances. southern Russia, Hungary, and Austria have large areas of loess lands, but the most remarkable occurrence of loess is that in northern China, where it forms the greater part of the surface; a uniform mantle of great depth, covering hill and valley alike, even on mountains several thousand feet high. It is extremely fine-grained, homogeneous earth, of brownish or yellowish color, and shows no sign of stratification. When cut, it stands with a vertical face, like a wall of masonry, though it crumbles in the fingers, and in north China whole villages are housed in elaborate excavations cut in the loess bluffs and these dwellings endure for centuries in a dry climate. Loess was caught and held by grassy surfaces, and has been made porous by the countless tiny channels left by the decaying stems and roots of grass. In areas that have long dry seasons, water rises through the soil to evaporate on the surface, and brings with it in solution the minerals essential to plant growth; and, owing to its porosity, loess has a self-renewing fertility that is in very marked contrast to most soils. In north China where the loess has been cultivated, almost without fertilizing, for thousands of years, its fertility remains unimpaired and a dense population, limited only by the dry climate, gathers on these lands. In southern China there is no loess and the area cultivated depends upon fertilizers; the population is so dense and the landholdings are so small, that it is impossible to feed live stock and the only available fertilizer is, in Mr. Pumpelly's phrase, "that produced by man." After a famine, or other calamity that has greatly reduced the population, recuperation in a loess district is rapid; but in the south, where it must depend upon the accumulation of fertilizer from a depleted population, recovery is slow. The recent terrible famine has visited the loess districts of northern China and was due to long-continued drought.

In his expeditions to central Asia, Mr. Pumpelly devoted especial attention to the mode of loess accumulation, and we may fittingly close with a few quotations from his report.

> "These observations showed clearly that all loess is primarily brought by wind and arrested by grasses under the protection of continued generations of which it slowly accumulates. But there are two sources from which the wind derives the dust. One is from the bare surface of deeply disintegrated mountains, as on the Pamirs, and the uninterrupted deflation by the winds of the rocks of the desert, which are perpetually disintegrating under the influence of the great daily changes of temperature. The other is from the flood plains and dry deltas of rivers and from the shores of retreating lakes. . . . This brings in water as an intermediate factor in transportation, in connection with the origin of loess in certain regions. In every case, however, the process must be in an arid or more than semiarid climate, where extensive rock areas or wide-spreading flood plains are in a state of desiccation. On the Pamirs we found the mountains buried in the unmoved products of their own disintegra-

tion. In this worst of desert regions, rocks at the surface crumble to dust continuously under the effects of the great and sudden differences of temperature between day and night, and between the sun-warmed and shade-cooled sides of the block. R. W. Pumpelly found the surface of the older moraines wind-swept to a floor of even smoothness, the large and small blocks of rock being represented only by flat surfaces flush with the floor, in which they produce the effect of a mosaic. Here we observed both factors at work in the process of loess transportation, for the waters from the early melting snows bring down great quantities of the finer products, which are sun-dried on the dry deltas and plains, and all through the day cyclonic columns of the dust are seen moving rapidly across the field of vision to disappear beyond the mountains. Again, in the great Alai grass-covered valley, 10,000 feet above the sea, at the northern foot of the Pamirs, we observed all stages of the process. Moraines of 1,000 to 1,500 or more feet high, and stretching 10 to 15 miles across the valley and belonging to the earlier glacial epoch, are mantled to a depth of several feet with loess, while the younger moraines, though abundantly grass-covered, have only a thin covering. The streams that descend from the snows and glaciers of the lofty Trans-Alai valleys have flood plains several miles wide, which are nearly dry except during the spring floods. Here one can often see the fine dust carried by the wind from the flood plains to the grass-covered moraines, and there can be no doubt that the loess on the moraines was brought by the winds from the neighboring flood plain. In view of this, it would seem probable that a great part, perhaps the greater part, of the loess of many regions has undergone previous transportation by water. The loess of China owes its origin, doubtless, both to deflation of the Mongolian deserts and to wind-sifting of the flood plain of the Yellow River, which carried an immense load of glacial flour during the glacial period.

"For the general reader, I will explain that loess is, with slight exceptions, the most important soil in the world, owing to its great depth, its fertility, and self-fertilizing power.

"Again, great events in our own history are directly connected with the distribution of this wind-borne soil—events which have shifted and radically changed the populations of Europe and have caused the downfall of empires and replaced civilizations by semibarbarism. For from north of the Caspian to Austria extends a continuous zone of loess lands covered with grass. From the time when the domestication of the horse and ox made possible the movements of organized bodies of men, these grassy plains have been used as an easy road for the migration of whole populations and for the devastating irruptions of barbarian hordes.

"Loess, whether originally a product of deflation or of glacial grinding, must, where its whole pre-æolian existence has been passed in desert conditions, retain a greater or less amount of the soluble products of disintegration and decomposition. For, even when leached and transported by water, more or less of these constituents remain in the silts left dry by evaporation, not only on desert depressions and dry deltas, but on broad flood plains as well."

The term "frost," as used in describing the destructive work of the atmosphere, means the freezing of water. On solidifying, water expands about one-ninth of its volume and, when confined in narrow limits, that expansion has a wonderful disruptive power. The bursting pipes of a cold snap in winter sufficiently convince the householder that freezing water acts like an explosive. The work of frost is a purely mechanical process and does not affect the chemical composition of the rocks; it is also very superficial and extends to no great depths in temperate climates, at most three or four feet of soil being enough to prevent it. In the polar climates, where the soil is permanently frozen to a depth of several hundred feet, the freezing took place once for all and only a foot or two at the surface thaws in the short Arctic summer. The destruction of rock by frost requires the indefinite repetition of freezing and thawing and thus, paradoxical as it seems, the destructive power of frost depends upon the heat of the sun. In moist climates, the surface rocks have water in all their joints and crevices and when the bare rock is exposed, as in cliffs and high mountains, the frost attack is of surprising rapidity and efficiency. The vast heaps and slopes of angular blocks of rock, quite sound and fresh and undecomposed, which occur at the foot of cliffs like the Palisades of the Hudson, or Kittatinny ridge at the Delaware Water Gap, or on any bare mountain peak where there is moisture, give eloquent testimony to the efficiency of frost destruction. Certain passes in the Alps are so bombarded by falling blocks riven off by the frost, that in winter they cannot be used, except in the early morning before the sun has melted the ice.

Frost destruction goes much farther than simply forcing large blocks out of the face of the cliff or peak and, by a continuation of the same process, breaks up the blocks into smaller and smaller pieces. On the summit of the pass by which the Union Pacific Railway crosses the Rocky Mountains, which, though relatively low, is yet more than 10,000 feet above sea level and has very low winter temperatures, the ground is covered for miles with frost-shattered débris of granite. Most of the pieces are less than an inch in diameter and yet are sound and fresh, the minerals with shining, undulled faces, which indicates that there is no incipient decomposition. The shattered rock, which looks almost like the product of a crusher, makes excellent ballast, for which the railroad company has extensively used it, simply using a steam-shovel to load it on the ballast trains. In this case, however, it is probable that the riving power of frost has been supplemented by another process described below; one does not find so finely divided frost-made débris of rocks which, like sandstone and limestone, are composed almost entirely of a single mineral.

Rain and frost are effective agents only in climates of considerable precipitation. In arid districts the rarely occurring rains are apt to be violent downpours and produce upon the bare, unprotected soil a disproportionate amount of destruction, but the sum total of its work is relatively small. It is the bare soil and the loose desert sands which in dry regions make the wind, which in moist, plant-covered lands is of little importance, the most efficient agent of rock waste. It does this by means of the sand and gravel which it sets in motion and abrades the hardest rocks, carving out the softer rocks in a fantastic fashion. The sand which is driven from the Libyan desert into the Nile valley before the prevailing westerly winds, pours down, in certain localities, over the bluffs of granite, in which it has carved channels like those made by the rain in clay. In fact, the sand blast, which is used in the engraving and cutting of hard substances like granite and glass, is employed by nature in desert regions. As a transporting agent, the wind carries sand and even fine gravel for considerable distances, but only fine dust can be carried very far.

A process which, in arid climates, closely simulates the action of frost, is due to the rapid changes of temperature which in such climates frequently follow sunset and sunrise. The naked rocks are highly heated by the sun and expand, as heated bodies must do, and, at nightfall, when a swift chill follows sunset, the cooled exterior of the rock attempts to contract upon the still expanded interior, and scales off in consequence. The talus slopes of arid regions, where the absence of moisture deprives the temperature of 32 degrees F. of its significance, are produced in this fashion, which has certain remarkable scenic effects. Livingstone mentions a range of hills in central Africa, which the natives feared as the abode of evil spirits; all night long the loud shattering of the heated rocks that went on explained the bad reputation of the place.

In rocks which, like granite, are made up of several different minerals in large grains or crystals, each different mineral constituent has its own particular rate of expansion and contraction when heated and cooled, and thus tends to separate itself from the surrounding grains, a tendency which grows stronger, the greater the range of temperature to which the rock is subjected and the suddenness with which the temperature changes. Eventually, this process shatters the rock into small pieces, and it is this oscillation of expansion and contraction which has probably cooperated with freezing water in producing the shattered Wyoming granite referred to above. Pieces of granite in Egypt, which for thousands of years have not been rained upon, but every day have been exposed to the burning hot sunshine and the chill of night, will often crumble upon light pressure. The writer well remembers his surprise, on picking up a piece of the granite casing at the foot of the third pyramid of Ghizeh, when it crumbled into small pieces under the pressure of his hand. The Egyptian obelisk, which was brought to New York and erected in Central Park in 1881, was threatened with complete destruction by the first New York winter to which it was exposed. The many centuries of daily heating and cooling under the Egyptian sun had so riven it with minute cracks and imperceptible flaws, that when rain water penetrated into these and froze, the granite began to scale and crumble in an alarming way. Fortunately, it was found possible to prevent the penetration of water by treating the granite with paraffin, and thus the obelisk has been preserved. Freshly quarried granite from Egypt would have shown no such weakness. Speaking of the deserts of central Asia, R. W. Pumpelly says: "Perhaps the most remarkable example of desert disintegration is found in the granite mountains ranging on the east. There whole mountains are fast crumbling to arkose and sand from which some few honeycombed slabs project as remnant wind-worn ridges. Such are the features wrought by an arid sun and shade with a range of 80 degrees F. from day to night."

Each one of the agents of rock destruction we have here considered—the sea, the river, the glacier, the atmosphere—produces different effects in accordance with the character of the rock masses which it attacks. There are, in the first place, differences according to the nature of the rock itself, whether igneous, sedimentary, or metamorphic. Then, there are innumerable differences in the arrangement of the rocks; in the case of sedimentary strata, the commonest kind of rocks, whether they are horizontal, tilted, folded, or faulted. Another set of differences are determined by the alternation of hard and soft rocks, because the soft rocks yield very much more rapidly to the attack of the destroying agents than do the hard. With these variable factors, it is not surprising that the land surfaces display an endless variety of topographical forms.

CHAPTER III

LAND FORMS DETERMINED BY ROCKS

IF allowed undisturbed activity, the final effect upon the land of the work of the sub-aërial agents is to remove all relief and cut the land surfaces down to low-lying base levels. In the long, slow process of base-leveling, great irregularities are caused by the more rapid removal of some portions of the rocks than of others. These irregularities are the relief of the surface, and, when relief has reached its maximum, it begins to grow less and less. We have seen how the topographical forms differ with the climate, or the preponderance of this or that agent of rock destruction and removal, and we have now to consider how these forms are affected by the nature and arrangement of the rocks.

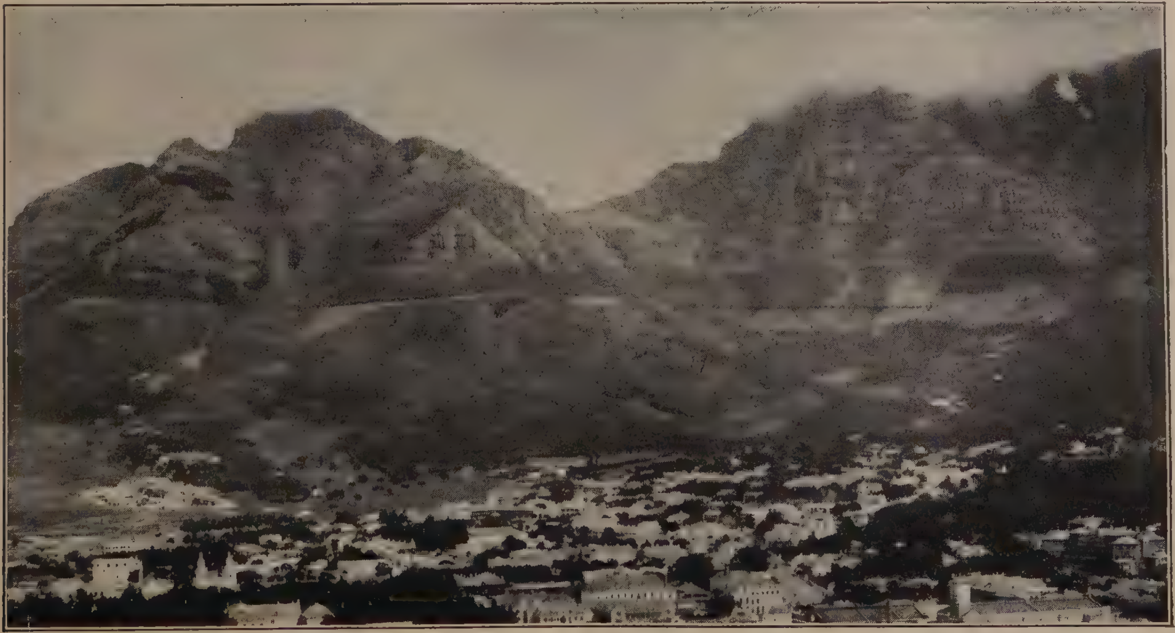
LAND FORMS IN STRATIFIED ROCKS

I. *In Horizontal Strata.* When a land area composed of horizontal beds is raised into a plateau, without folding or steeply tilting the beds, the streams, which are speedily established upon the new land, begin to cut their cañons in the form of deep, vertical-sided trenches. Atmospheric weathering gradually widens the trenches into broad valleys and the resultant forms are determined by the alternation of harder and softer beds. If the beds are relatively resistant, especially if hard rocks form the surface, the extension of the valley system will cut up the plateau, which is then said to be "dissected," into a series of flat-topped table mountains, which in the Southwest are called by the Spanish term of "mesa." The height of the tables is determined by the depth of the valleys and that, in turn, is regulated by the height of the plateau above sea level, for, save in desert basins that have no outlet, rivers cannot excavate their channels below sea level. Further wear—the attack from many sides simultaneously—gradually converts the table mountains into pyramidal and even into conical forms, as shown in the isolated fragments of the plateau which rise in the Colorado Cañon, mountainous masses which are dwarfed by their surroundings.

If the whole mass is soft and easily removable, the rocks will weather into dome-shaped and round-topped hills. Examples of the forms produced by the weathering of soft, horizontal strata, with a few harder beds alternating, are afforded by the Bad Lands of the semiarid West. The term "bad lands" is the translation of part of the old French name, "mauvaises terres à traverser," given to these curiously torn and gashed areas by the early French explorers, who had discovered the great White River bad lands of what is now South Dakota as early as 1746. Seen from a high point, from which the observer can look out over a wide area, bad-land scenery is extraordinarily grotesque and shows a wild chaos of peaks, ridges, knifelike crests, and flat-topped tables, all of which is due to the cutting out and weathering of horizontal beds of soft rock, chiefly by the action of the rain. The traveler who looks upon bad-land scenery for the first time, almost always feels a sense of unreality, as though he were wandering in some strange dream. Some portions of the rocks are much harder than others and stand out in relief, while the softer are first removed. The bad lands are most extensive in Montana, the Dakotas, Wyoming, and Utah.

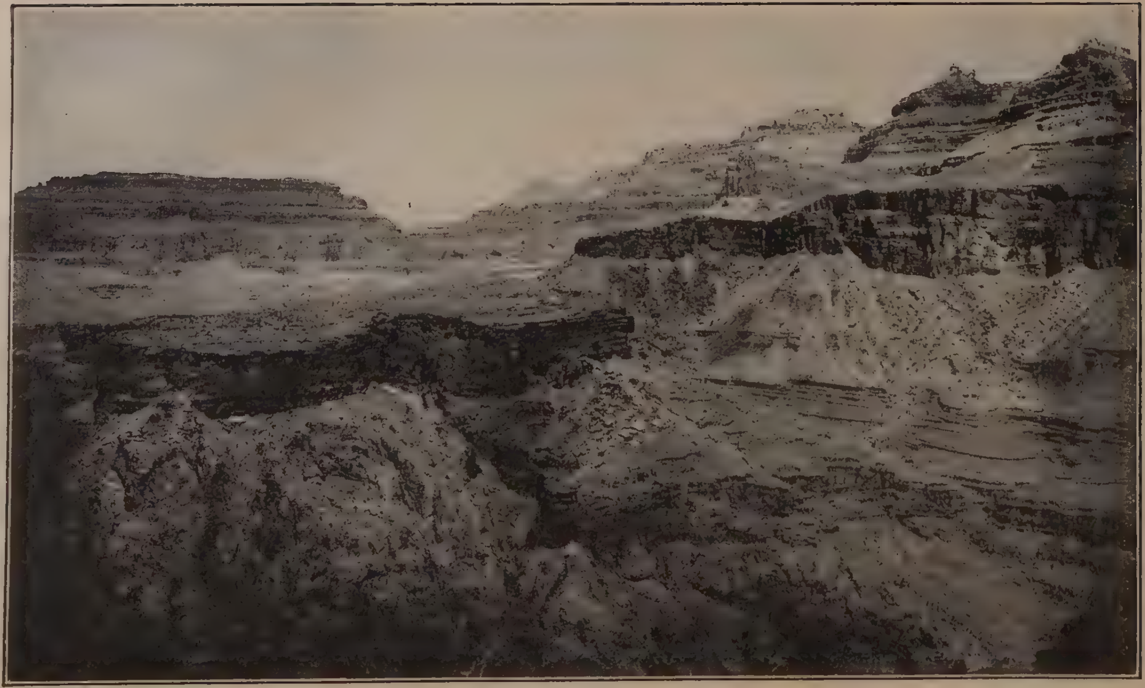
Harder rocks in similar climates give rise to vertical-sided tables, such as the mesas which are so abundant in various parts of the Southwest, from the plains of Kansas into Arizona and especially in New Mexico. A mesa may be a great table-land, with a summit area of thousands of square miles, or it may be a mere tower, with dimensions of only a few feet, but, in practice, the name is usually given to vertical-sided masses of moderate dimensions. In South Africa the "kopjes," of which so much was heard during the Boer war and which played so important a part in the strategy and tactics of that war, are generally mesas of sandstone, usually with somewhat sloping sides and flat tops. Often the kopje owes its existence to a cap of hard lava, called a "krantz" or "wreath," which has protected the softer sandstone beneath. The kopjes are the remains of a dissected table-land, most of which has been swept away, and the kopjes measure the amount by which the general level of the country has been lowered, though, of course, great thicknesses of rock above the level of the krantz may have been removed without leaving a trace.

If more resistant rocks occur beneath the softer ones, a change in topographic forms will occur when the harder underlying rocks are partially exposed. In the soft rocks, the valley sides have gentle slopes, but, when the harder rocks are reached, their faces



Copyright, Publishers Photo Service

TABLE MOUNTAIN (RIGHT) FROM CAPETOWN, SOUTH AFRICA, WITH CLOUD TABLECLOTH IN PLACE



DOWNFAULTED BLOCKS BETWEEN BRIGHT ANGEL AND TRINITY CREEKS,
COLORADO CANYON

become steep, or even vertical. When hard and soft strata alternate in the wall of a valley, the soft beds form gentle slopes, which connect the steep faces of the hard rock.

Sometimes the appearance and effect of horizontality are given by very broadly and gently folded strata, an interesting example of which is afforded by the Uinta Mountains of northern Utah. These are formed by a single great arch, and the curvature is so gentle that, except near the foot of the range, the beds, in any given view, appear to be horizontal; they are also of great thickness, many thousands of feet. Out of these thick masses of almost level strata the subaërial agents have carved the great variety of peaks and pinnacles, pyramids, domes, ridges, and glacial amphitheaters, which, as the range rises above the level of perpetual snow, give to these mountains an extremely picturesque and beautiful character and can be seen for long distances across the level top of the high plateau from which the range rises. Talus slopes of frost-riven blocks occur on a gigantic scale and give some conception of the amount of material that has been removed in sculpturing the mountains. The rivers that penetrate the range have cut out profound and gloomy cañons, thousands of feet in depth.

Another very striking instance of topographical forms in horizontal strata is given by the Grand Cañon of the Colorado in northern Arizona. This gigantic river trench has been cut to a depth of 6,500 feet through the almost horizontal strata of the high plateaus. The cañon consists of an outer gorge, ten to thirteen miles or more in width and about 5,000 feet deep, then a broad flat floor, which leads to the inner gorge, only half a mile or less in width. The walls of the outer gorge have been marvelously sculptured by frost, rain, and wind into a profusion of architectural forms, reflected in the names given to a few of the more conspicuous of them, such as "Vishnu's Temple." Many of the beds are richly colored; and the combination of vast scale, infinite variety of form, richness of coloring and wonderful atmosphere, makes one of the grandest spectacles in the world.

II. *In Inclined Strata.* Beds which have been tilted or inclined give rise to a class of forms which are entirely different from those carved out of horizontal strata. It nearly always happens that in thick masses of tilted beds some of the strata are notably harder and more resistant than most of the others. In this case the softer beds will be more rapidly removed, leaving the harder strata standing in relief where their inclined edges come to the surface. These truncated edges of the stronger beds form lines of bluff or cliff, dependent upon their height, which, in turn, is determined by the thickness of the resistant beds and their angle of inclination. If there are several of these harder beds, the landscape is traversed by long lines of parallel bluff or cliff, each of these lines indicating where a harder bed, or group of such beds, reaches the surface. These projecting masses are, of course, not immune to the attack of the destructive agents, and so they generally take on a more or less sinuous and winding course, though their general direction is straight. Under the attack of rain and frost and the undermining action of springs, the cliffs slowly retreat in the direction in which the strata incline. Because of this inclination, the cliff is lowered as it retreats, which is not true of horizontal strata; and the more nearly the country is cut down to base level, the more are these cliffs diminished in height. If the region, the topography of which is determined by inclined beds, is in a climate of normal rainfall, the usual network of streams will be established upon it, and their courses and directions of flow will be determined in a manner to be explained in a subsequent chapter. In one way or another, many streams will cut across these lines of cliff in cañons and gorges, which, in the course of time, will be broadened into sloping valleys. When the topography is mature and relief has reached its maximum, we find the country traversed by parallel lines of cliff which, though more or less winding, are yet very constant in general direction. From one line of cliff to the next, the surface of the land slopes gently, the angle of slope being determined by the inclination of the strata; for the hard strata, the truncated edges of which are the cliffs, form the sloping surface of the land, though ordinarily concealed under a mantle of soil. The cliffs are breached by many streams, and these notches or passes form the natural highways which are, in a measure, compelled to follow the river valleys.

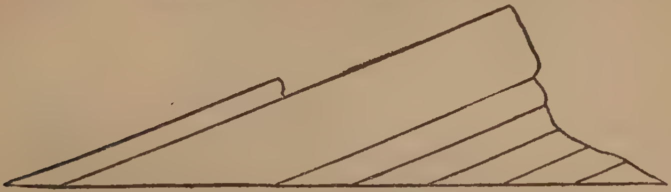
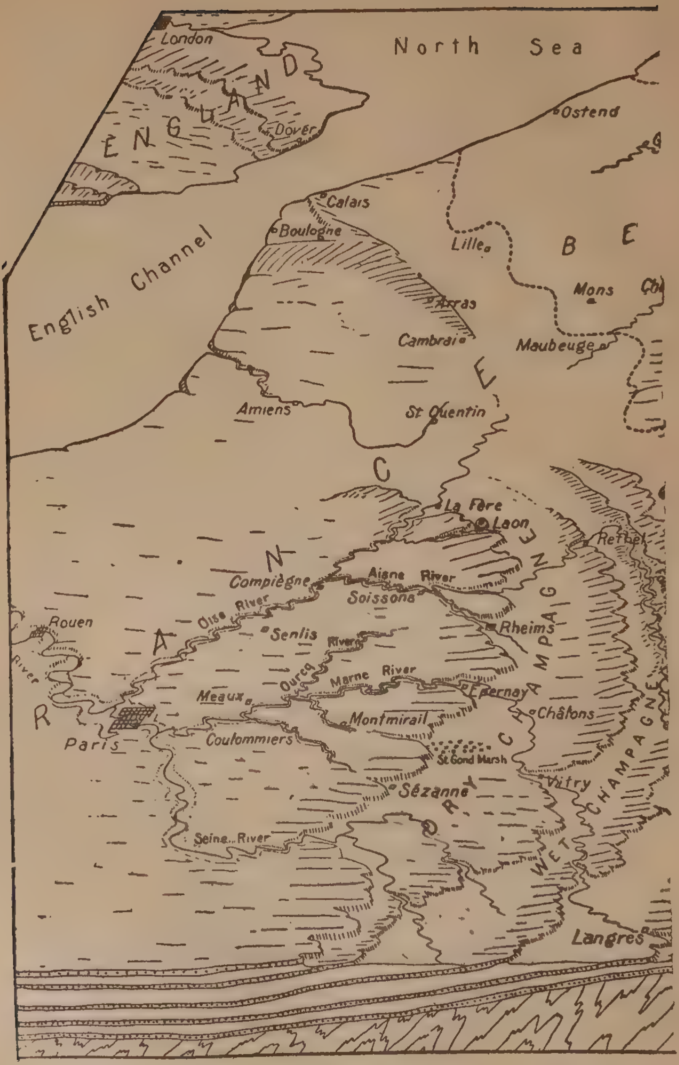
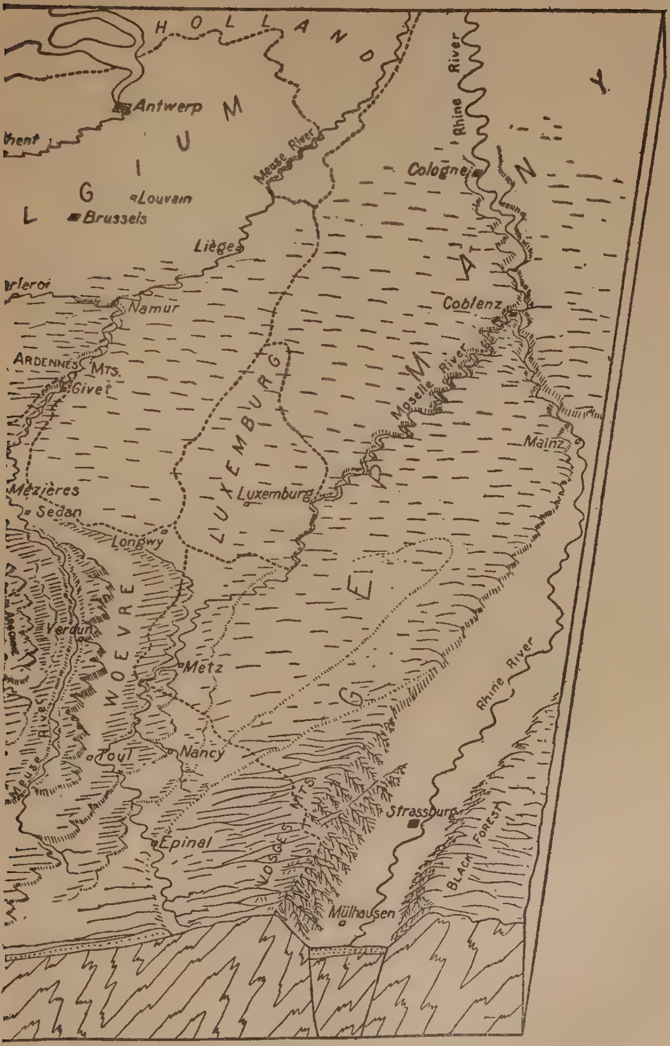


DIAGRAM SHOWING ESCARPMENT AND DIP SLOPE IN SEDIMENTARY BEDS



MODELED MAP OF BELGIUM, NORTHERN AND
(*After Prof. D. W. Johnson, by*
The section seen on the lower border of the model displays the
made by the harder beds as they reach the surface. The very
Forest and the Rhine Valley as far as Mainz



EASTERN FRANCE AND ADJOINING AREAS

permission of the Amer. Geogr. Soc.)

underground rock structure and shows how the escarpments are ancient, intensely folded rocks form the Vosges Mountains and Black is a rift made by two parallel faults.

Structures like those described are found on a stupendous scale in some of the high plateaus of Arizona and Utah, where the escarpments of the cliff lines are from 1,500 to 2,000 feet high and the gentle slopes of the land surface from one line of cliff to the next are from twenty to sixty miles in breadth. The imagination reels, when one calculates the incredible amount of rock material which must have been carried away to give rise to the present topography. There can, however, be no reasonable doubt as to the course of the operations that actually took place, not at all incredible when one remembers the immensity of geological time.

On a very much smaller scale, but of incomparably greater human interest, is the topography of eastern France, which is the outcome of inclined strata and of a certain, definite and particular alternation of stronger and weaker strata. The German scheme of attack and the French plans of defense were alike conditioned by the topography of the country in which military operations were to be carried on. From August, 1914, to November, 1918, the world in agonized suspense watched the stubborn struggle in eastern France, though but few people comprehended what a vital part in that struggle was played by the inclined strata of the French upland. If a great trench could be dug in a straight line from a point south of Paris to a point on the east side of the Rhine, the side of that trench would show the arrangement of the rocks which underlie France and Germany west of the river. It is not necessary actually to dig the trench in order to obtain this knowledge of the rocks; surface observations properly made and used by competent geologists will answer every need. At the bottom of our imaginary trench we should find a mass of strata of great geological antiquity, which have been compressed and crumpled into folds. Lying upon these folded rocks is a body of strata of very much later date, which have been but slightly disturbed from the horizontal attitudes which they assumed when they were deposited on the floor of the sea or other body of water, sometimes fresh, sometimes brackish. The surface of the ground, formed by the top of this upper and younger series of strata, is a very shallow basin, the Basin of Paris, sloping to the center, but with the margins upturned, so as to tilt the strata and bring the harder ones to the surface in successive lines of cliff or escarpment, all of which present their steep faces to the eastward and their gentle slopes to the westward. The steep eastern faces are irregular and winding, with many wooded ravines cutting into them and breached at many points by river valleys, thus forming gateways for roads and railways which were of supreme military importance. In the center of the basin upland, where the strata are nearly or quite horizontal, the rivers like the Marne and the Seine have cut their trenches 300 to 500 feet deep and form serious obstacles to the advance of an army. Two rivers, the Meuse and the Moselle, run to the northeast, the Moselle joining the Rhine at Coblenz (Roman *Confluentes*), and the Meuse, which on entering Holland becomes the Maas, flowing into the North Sea at Rotterdam. Along the belt of country west of the Rhine, which extends from the Swiss frontier into Belgium, and belongs to France, Germany and Belgium, the more ancient folded rocks rise from under the covering of newer strata and form a series of mountains and plateaus. On the south end of this belt are the Vosges Mountains, and then to the northward the rugged country of western Germany which has various names, such as Schiefergebirge, the Eifel, etc., ending in the Ardennes of southern Belgium. East of the Vosges Mountains is the broad, deep, flat-floored valley of the Rhine, which in this middle part of its course was not cut by the river, but is a rift valley, or trough fault, with the upthrow on the west forming the Vosges Mountains and on the east the Black Forest.

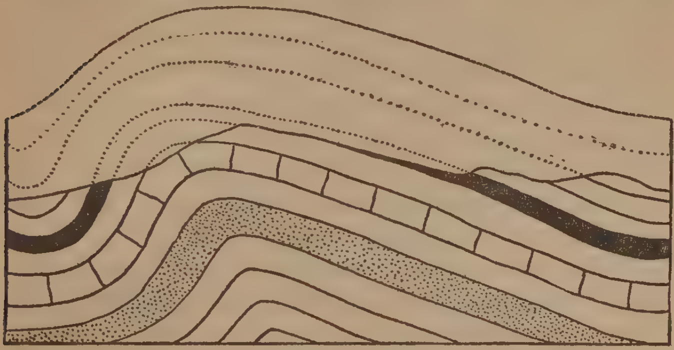
The topographical lines do not follow the frontiers, and the outermost line of defense was partly in France, partly in Germany, partly in Belgium; but the French promptly seized the southern Vosges in Alsace, as they had a gentle ascent to the summit, and the passes. Owing to the steepness and height of the eastern side of the mountains, the French troops held this line and the Germans entirely failed to dislodge them. The second line, which is an escarpment formed by the outcropping of hard beds in the newer, gently inclined rocks of the Paris basin, also cuts across the frontier as it was in 1914. The Moselle cuts a gap through the cliffs, which is guarded by Metz, and in French territory is Nancy on the same scarp, with two openings. The crest of the scarp, near Nancy, called the "Grand Couronné," was fiercely assaulted by the Germans, and its successful defense by the French was one very important element in winning the battle of the Marne. The third line (second in the newer rocks, counting from the east) is the Toul-Verdun line. The German attack in February, 1916, led to several months of the most tremendous fighting of the war, but the line of natural defenses held. The plain at the eastern foot of this scarp, called the Woevre, has a deep clay soil, which in wet weather and throughout the winter becomes a bog and adds greatly to the defensive strength of the scarp. In the first rush of 1914, the invaders broke through this scarp where it is narrowest and weakest and established the famous St. Mihiel salient, which they held until driven out by the American attack in 1918. A fourth line is the Argonne Forest, a fifth the line of the Aisne, the line of Vitry and Rethel, and the sixth is in Champagne with Rheims and Epernay guarding the points where the scarp is breached by river valleys. Tracing these escarpments northward, they are found gradually to descend into the plain which forms the north of France and Belgium and, in fact, extends across north Germany far into Russia, the great plain of north Europe.

In speeches and writings, the Germans have given to the world the essential features of their plan of campaign in "the war of two fronts." Assuming that Russian mobilization would be slow and that no invasion from the east need be apprehended for several weeks after the hostilities began, the plan was to concentrate an immense host in the west and crush France beyond all hope of recuperation, before turning to meet Russia, which, in the meantime, could be kept engaged by Austria. The essential feature of this plan was speed of execution, to destroy or capture the French armies before those of Russia could become formidable. By taking the road through Belgium, the right wing of the German army would have a clear and open road to Paris, with hardly a topographical obstacle to bar the way, and, trusting in the guaranteed neutrality of Belgium, the French had not fortified that part of their frontier, though spending vast sums on the fortification of the German border. The advance through Belgium would thus turn the lines, both of the artificial fortresses and of the natural defenses, and was thus decided upon. At first, the narrow gateway between the Ardennes and the Dutch province of Limburg was blocked by the forts of Liège, which resisted the infantry assaults until the great Austrian siege guns were brought up. Then the forts were speedily destroyed. Namur, guarding the important junction of the deep valleys of the Meuse and the Sambre, shared the same fate, and the way to Paris was open.

The French, promptly learning that the new guns rendered permanent fortifications useless, removed the guns from their forts and resolved to confide in field works and the natural defenses which the geological structure of the country gave them. It is no disparagement of the skill of French generals or the valor of French troops, to say that these natural defenses saved France from disaster, for the French were so greatly outnumbered that they could not have held a country of open plains long enough for the British to come to their help effectively. The skill and valor were abundantly displayed, but they took advantage of the natural lines of strength, which the new artillery was powerless to destroy. The course of former wars was determined by similar considerations; Marlborough in the early eighteenth century and Wellington in the early nineteenth followed nearly the course taken by Von Kluck, and for the same reasons. It is a commonplace of military science to say that strategy is conditioned by topography. This was convincingly illustrated in northeastern France from 1914 to 1918.

III. *In Folded Strata.* The history of folded beds is usually more complex than in the case of horizontal or inclined strata, and the latest views on the elevation of mountain ranges tend to increase the complexity. The topography which is due to folding alone is a series of parallel ridges, with rounded, saddlelike summits and separated by troughlike valleys; the ridges are formed by the upward, and the valleys by the downward, arching of the beds. Sometimes, but rarely, as in the case of the Uinta Mountains, there may be but a single upward arch, or an oval dome, as are the Black Hills of South Dakota. As the formation of a series of folds has never been observed, and as no instance is known in which the topography is due to folding alone, entirely unmodified by denudation, it is impossible to say precisely what such a topography would be; the way in which rivers have cut down through folds which were rising athwart their course is eloquent proof of the extreme slowness with which folding is carried on. It may well be that there never was a pure and unmodified topography of folding, because denudation would begin as soon as the folds began to rise above the surface. An example in which folding is plainly the controlling factor in determining the land forms is afforded by the Jura Mountains of Switzerland, the most thoroughly investigated of all mountain ranges. In these mountains the ridges are formed by the upward arching folds and the longitudinal valleys by the downward folds. The length of the range is given as 192 miles and it consists of ten or twelve parallel lines of ridge, more in some transverse lines, fewer in others. None of the ridges has even nearly the full length of the mountain uplift; and though one has almost exactly half this length (97 miles), most of them are from 2½ to 55 miles long, and as they end, are replaced by others. This is not peculiar to the Jura, but is true of mountains of folding generally, and shows with great clarity in a relief map of the Appalachians. This simple topography has, as yet, been but little modified by the destructive agents. A considerable thickness of beds that are still intact in the valleys has been removed from the ridges, materially reducing their height; and many transverse valleys, cutting through the ridges and connecting one longitudinal valley with another, have been excavated by the rivers. This extraordinary behavior of rivers, according to which they seem to avoid the easy and to choose the difficult course, will be dealt with in a later chapter (Chapter VI). Here it will merely be noted that the number of these cross valleys in the Jura is already very large; Supan's sketch map of the headwaters of the Birs shows that the stream and its branches have cut no less than twenty-one such valleys through the ridges. In young mountain ranges, in which folding still controls the surface forms, the topography is said to be structural, or tectonic, a Greek word of the same meaning.

If the folding is comparatively gentle, so as to produce undulations or sweeping curves, the tendency of the denuding agents is to reverse the original topography of folding, cutting out the valleys along the ridges of upward arching and leaving the bottom of the downward arches, the original valleys, as the top of the new ridges. This, like many other facts of topography, appears at first sight to be extremely paradoxical and yet, when carefully studied, is seen to be natural and simple enough. On the convex side of the upward arch the rocks were stretched apart and more or less shattered, and are therefore favorable subjects for attack; whereas in the downward arch they are compressed and made harder and more resistant. The beginnings of this reversal may be observed in the Jura, where a stream has cut a transverse valley through a ridge which is covered with a hard bed, but is made up of weaker rocks beneath the hard layer. These weaker rocks are rapidly cut out, undermining the hard bed and beginning a new longitudinal valley. In such cases, the stream enters and leaves the ridge by a narrow gorge through the hard rock, but between these gorges the valley opens out widely. Eventually, streams



ANTICLINAL FOLD

An anticlinal fold, before and after erosion. The dotted outlines between the crest of the fold and solid line that represents present surface indicate beds that have been removed by erosion. The broken line indicates original crest of fold.

are established in these new valleys and then they lengthen rapidly. In very old mountain ranges, this reversal, converting the valleys of folding into ridges and the ridges of folding into valleys, is abundantly illustrated.

If the folding has been more intensely compressive and the folds are closely crowded together, the upward arches, or saddles, persist longer as ridges. The wearing away of the crest of the arch gives rise to subordinate and secondary lines of ridge and valley within the limits of each original arch, the secondary ridges being formed by the projection of the harder and stronger beds, and the secondary valleys carved along the weaker and softer strata. While the persistence of the original ridges of folding is longer than in the gently folded rocks, the continuance of denudation brings about the same result eventually, either wearing the whole mountain mass down to an approximate plain, or reversing the original topography. It is a significant fact that all the very high mountains of the earth, such as the Alps, the Himalayas, the St. Elias range of Alaska, the Andes, are ranges which are, geologically speaking, youthful; while ranges which can be proved to be of great geological antiquity, like the Armorican range of France, the German ranges, the Urals, and the Appalachians, are low and frequently display reversed topography.

If areas of folded rock, which have been worn down to sea level, are reelevated, all the processes of destruction, more particularly the rivers, are rejuvenated and begin a new cycle of their operations. Such a smoothed and re-elevated mass is a plateau, but is built of folded, not horizontal, strata.

This does not necessarily imply that all plateaus composed of folded beds have been planed down and reelevated; Tibet, the loftiest of all existing table-lands, is folded, but probably not reelevated, though some plateaus, like the upland of New England, have had such a history. The surface of plateaus of this character is formed by the worn and truncated edges of folded or inclined beds; and as they had been, before reelevation, reduced to base level and could not be cut any lower, hard and soft beds are at the same level. In the second cycle of development, the carving of the surface of this reelevated plateau, first into relief and then smoothing away this relief, the same laws will be found to govern the topography as in the first cycle, namely that the ridges of this second cycle are caused by the projection of the harder and stronger beds, and the valleys are cut out along the softer ones. These principles are again beautifully exemplified in the Appalachians which have, at least twice, been worn down nearly to base level and then upwarped into very gently sloping, dome-shaped surfaces, which departed but little from horizontality, having the highest point in Virginia and sloping very gradually north and south from that summit. At a few points, notably in western North Carolina, hills of considerable height had been left standing when the reelevation took place, and therefore they are now the highest parts of the whole mountain area. Mount Mitchell in North Carolina is the highest point of land east of the Missouri River; it was one of the residual spots, which for some reason was not worn to base level.

A very characteristic feature of the Appalachians, as they are to-day, is that their long lines of ridge are not cut into peaks, but continue their even sky line unbroken for many miles, interrupted only by the "water gaps," where rivers flow through the ridge, or "wind gaps," which have been deserted by the streams that made them. To one who is familiar with mountain scenery, the contrast between these long, level, unbroken sky lines, and the jagged, irregular and serrate sky lines of most mountain ranges, the Uintas, for example, is very striking and very puzzling. Like most topographical enigmas, the explanation is to be found in the history of the region. An observer standing on some high point that commands a very extensive view over the many parallel Appalachian ridges can easily reconstruct the freshly reelevated plateau, before its surface had been carved into the existing relief of ridge and valley. He need only, in imagination, fill in the intervening valleys and he will see, not only that each separate ridge has an even, almost level summit, but that all the ridges rise to nearly the same level and that a very gently warped surface would touch them all. An examination of each ridge and valley will show that the ridges are made of the hard rocks, and the longitudinal valleys, which are parallel with the ridges, are cut out along the soft rocks. In other words, the hard, strong rocks have suffered but little from the attack of the denuding agents and still preserve the level of the reelevated plateau. Deep valleys have been scooped out along the weaker rocks in the time which has left the hard ridges almost unaffected. Of course, in such a view as has been imagined, the observer could not see the dome with its summit in Virginia; to ascertain that a regular survey, with an accurate determination of heights, is requisite.

The Appalachians further illustrate what some geographers call the "grain of the country" from the analogy of the grain of wood. Following the ridges or the valleys, the traveler may keep on the same kind of rock for many miles, while, if he walks across the ridges, or through the gaps in them, he is continually passing from one kind of rock to another. Rivers which, like the Delaware and the Susquehanna, flow across the mountains, are said to flow across the grain of the country, while the coast line of the Middle and Southern States follows the grain.

Folded areas are usually, not always, long and narrow belts. All true mountain ranges are folded, but not all folded areas are sufficiently elevated to be mountains; the difference is merely one of altitude.

LAND FORMS IN IGNEOUS ROCKS

The igneous rocks may be conveniently divided into two groups, which are called respectively volcanic and plutonic. The volcanic are those igneous rocks which reach the surface in a molten state, or in the form of fragments resulting from explosions within the volcano. These fragments vary in size from huge blocks, weighing many tons, to the finest and most impalpable dust, which is carried hundreds of miles by the wind. The molten material which supplies volcanoes has ascended from unknown depths, forcing its way through overlying rocks; but in many instances this molten material did not reach the surface, but solidified at varying depths below the surface in masses, great and small, the shape and size of which are determined by the place which they could make for themselves in the overlying rock cover. The fragmental products of explosion are never found as plutonic bodies. As plutonic rock masses were formed underground and yet a great many of them are found at the surface, their exposure is due to denudation, which has removed the overlying rocks. As this stripping away of the rock cover requires a very long time, most of the known masses of plutonic rock are very ancient, geologically. When circumstances have been especially favorable and denudation exceptionally rapid, plutonic masses of comparatively late date have been laid bare.

I. *In Volcanic Rocks.* Volcanic topography is primarily constructive, being caused by the volcanic materials which have risen from below and are piled up on the surface of some area, either on the land or on the sea bottom. Nearly all volcanoes build up cones around their vents, the height and diameter of which are determined by the length of time that the activity of the vent continues. Some very lofty mountains are volcanic cones, while other cones are not more than forty or fifty feet high, the vents dying out after a single brief eruption. The shape of the cone is conditioned by the nature of the material of which it is composed. The so-called "cinder cones," which are due to the piling up of fragmental materials, are usually very steep and of extremely graceful shape, like the famous Japanese peak, Fuji San. Most volcanic cones, like Vesuvius and Etna, are of a mixed character; while owing their shape chiefly to fragmental material, they contain much lava in the forms of sheets and dikes, the latter vertical walls of solidified lava that has filled up fissures in the cone. The well-known peaks in the Cascade Mountains of Oregon and Washington, like Mount Hood and Mount Rainier, owe their beautiful shape to the symmetrical piles of volcanic fragments which have been built up around the vent and to such a height that their tops are snow-covered for some thousands of feet below the summit. These fragmental cones have been very successfully imitated by blowing sawdust up through a hole in a table top by means of compressed air. The grains of sawdust fall back around the vent in a perfect, conical form.

Cones exclusively built of lava-flows are much less frequent and their shape is dependent upon the fluidity of the lava, which determines the distance to which the lava flows before it stiffens and comes to rest. Mauna Loa, in the Hawaiian Islands, is 14,000 feet high, but so exceedingly gentle is the slope that at sea level the cone is eighty miles in diameter. But the part of the mountain above sea level is less than half its total mass; Mauna Loa is one of the four cones which make up the island of Hawaii, and which have been built up from the sea floor where the water exceeds 2,500 fathoms in depth. Measured from the sea bottom, the mountain is 30,000 feet high and 200 miles in diameter at the base. In these cones fragmentary material is almost entirely lacking.

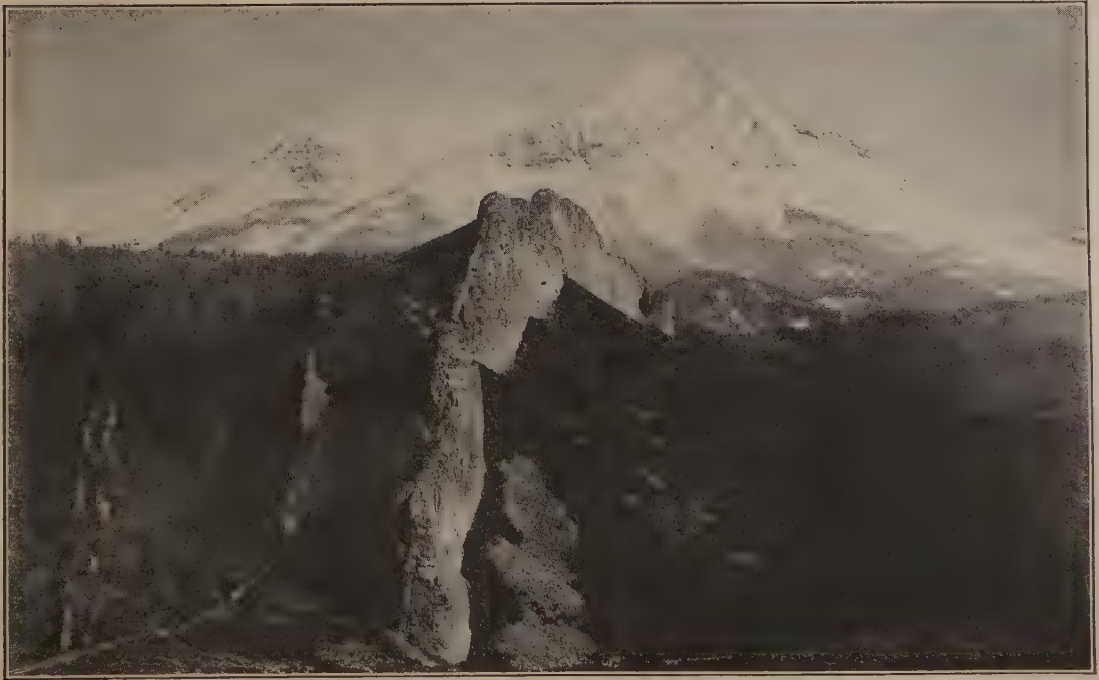
Like all other mountains, volcanic cones are subject to denudation, but so long as the volcano is active, the processes of accumulation preponderate and the cone continues to grow, unless a violent explosion rends it to pieces, as has frequently happened. Sometimes the explosion blows off the top of the mountain, thus forming a crater ring, which may fill with water and become a crater lake. The wonderful Crater Lake in southern Oregon, which has fortunately been made a national park, was not formed by an explosion, but by the falling in and engulfing of the upper part of the cone. A cinder cone built in the sea is speedily cut away by the waves as soon as activity ceases; it may be a matter of a few months or weeks. On land, destruction is much slower but quite as sure, and in many parts of the world we find volcanic cones in all stages of degradation and removal. Often the destruction is so complete that it is extremely difficult to recognize and reconstruct the original form. The remarkable volcanic fields of Arizona and New Mexico, which have only extinct vents, display cones in all stages of degradation; some are perfect cones, which have suffered hardly any loss. The beautiful, snow-capped San Francisco Mountains (near Flagstaff, Arizona) are a craggy mass of peaks, which do not immediately suggest their volcanic origin, because of the manner in which they have been dissected. From these down to hardly recognizable remnants there is every transition.

Another manifestation of vulcanism is on so gigantic a scale, that it is difficult to see how such enormous masses of molten rock could have reached the earth's surface. This is exemplified in the lava plains and plateaus which cover so much of Idaho, eastern Oregon and Washington, with an area of nearly two hundred thousand square miles. The old topography of the region has been completely obliterated, the valleys filled with several hundred feet of black basalt and the hills buried out of sight. After solidifying, the lava formed an almost level surface of black rock and, as yet, the new topography has been but little modified. Geologically speaking, this flooding of lava is a comparatively recent event, but it took place some millions of years ago. The rivers have cut their trenchlike cañons through the lava and into the underlying soft rocks, and some of these valleys, like that of the John Day River, have been widened considerably. Owing to these deep, steep-sided cañons, the region is a difficult one to cross, but the traveler who looks across its surface is unable to see these trenches and imagines that he can easily traverse it in any direction. In a less arid climate, no doubt, the dissection of the plateau would have been carried farther.

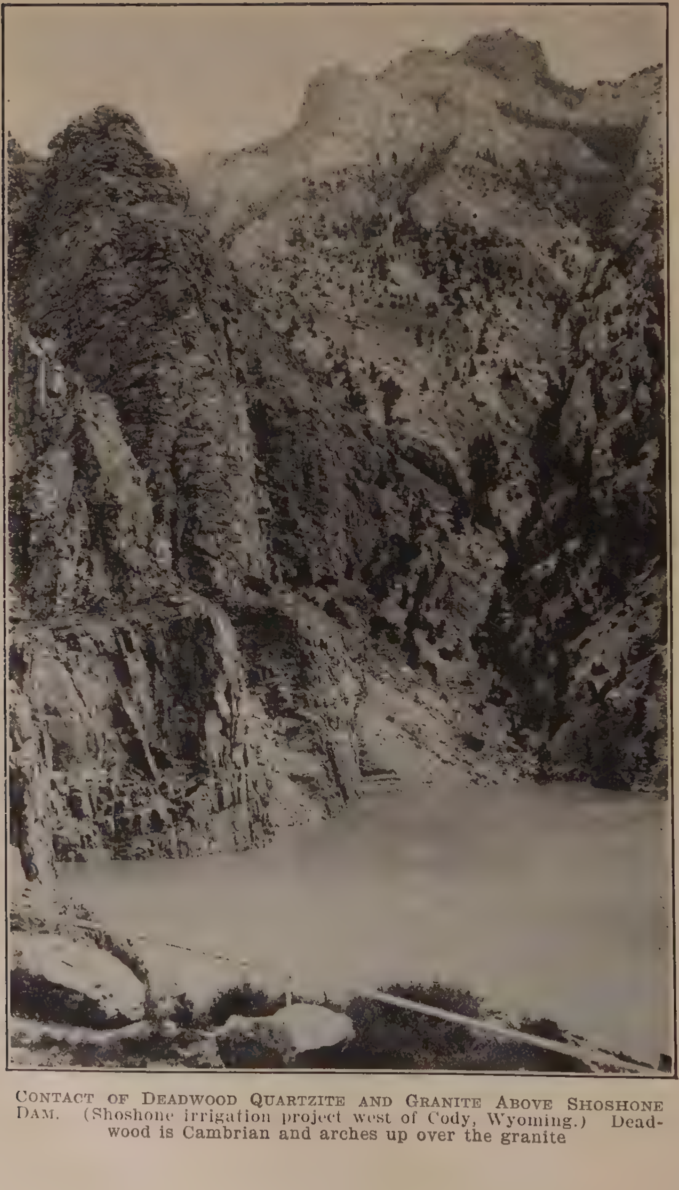
A similar and even larger mass of lava, piled up in successive sheets by different outpourings, occurs in the Deccan in India, and another one in East Africa. The African lavas are thus described by Gregory: "On reaching the summit of the last ridge of the Iosti Mountains, we found before us a vast expanse of undulating prairie, stretching away to the western horizon. The rock of which this consisted ended abruptly against the flank of the old gneiss ridge, but it ran up the valleys and into the hollows of the mountains, just as the water of a lake follows the irregularities of its shore. So much did this view remind me of that across the great Snake River lava fields of Idaho, when seen from the range of the Tetons, that I felt sure at once that this was a plain of lava and not of alluvium. I hastened down to it and the inference was confirmed. The resemblance between this plain and the American lava sheet became still more apparent as we marched across it."

The dissection of a lava plateau by streams and the atmosphere is carried on as though the sheets of lava were horizontal strata of sedimentary rock, except that lava is much harder than most sedimentary rocks. In the west of Scotland and the north of

Ireland is a lava plateau which has been so deeply dissected and cut to pieces, that its original character can with difficulty be recognized. The celebrated Giant's Causeway, in the north of Ireland, is a fragment of this plateau. What especially distinguishes the Columbia River lava plateau (as the one in our northwestern States is called) is the youthfulness of its topography. So far, only the first step in its dissection has been taken, the trenching of the lava by the river canons and the incipient widening of some of these into valleys. As a rule, there is little that is characteristic in the topography formed by the fragmental products of volcanoes, save as they are piled up into cones. The volcanic dust, ash, and other fine materials, sometimes remain loose and incoherent, and sometimes compacted into rock of greater or less firmness. They also are, topographically speaking, the equivalent of stratified rocks of similar hardness and thickness. Indeed, many of them are truly stratified by the sorting action of the wind or of the body of water into which they were showered. The material is of igneous origin, the arrangement of it sedimentary. There is, however, a highly characteristic volcanic accumulation, which has some resemblance to the till or bowlder clay of glacial origin, consisting of large blocks of rock, or rounded bowlders, imbedded in fine material. It is not spread out over vast areas as a relatively thin sheet, like the till, but piled up in thick masses, of no very great extension horizontally. The Absaroka range, on the eastern side of the Yellowstone Park, is, in very large degree, a huge pile of volcanic material of this description, and the weathering of it has given rise to some of the most fantastic topography known to man. On account of these fantastic



WEST SPANISH PEAK, COLORADO, FROM THE NORTHWEST, SHOWING DIKES THAT CUT THROUGH FLAT-LYING EOCENE STRATA. (*U. S. Geological Survey*)



CONTACT OF DEADWOOD QUARTZITE AND GRANITE ABOVE SHOSHONE DAM. (Shoshone irrigation project west of Cody, Wyoming.) Deadwood is Cambrian and arches up over the granite forms, the region is known as the "Hoodoo Country," which well expresses its unearthly character.

II. *In Plutonic Rocks.* By definition, the plutonic rocks are those which, though originally molten and more or less fluid, did not reach the surface of the earth, but solidified at various depths below it. While they did not reach the surface, the surface has frequently been so removed by denudation as to expose the plutonic bodies, especially if the intrusion of the molten rock has taken place in rock masses high above sea level, or which were subsequently raised to great altitudes. *Intrusive* is a term which is frequently used for plutonic, in contradistinction to *extrusive,* another word for volcanic. The rock which the plutonic bodies invade, or into which they intrude, is called the country rock and is usually, but not always, sedimentary, and is generally converted into metamorphic rock along the contact with the hot masses.

Both in size and shape, the various plutonic bodies differ greatly from one another; they may be only a few feet or hundreds, perhaps thousands, of miles in diameter. As a general rule, the plutonic masses are harder than the intruded country rock, and therefore stand out in relief when denudation has worn the surface down so as to expose them. It sometimes happens, however, that the country rock is harder and stronger than the intrusive rock, and then the latter wears away more rapidly and depressions are formed instead of prominences. This would seem to be largely a matter of the chemical composition of the rock and of climate; and though the question has not yet been sufficiently investigated for a decisive answer, there is reason to believe that in warmer latitudes rain has a greater chemical efficiency in decomposing the complex minerals that chiefly make up the igneous rocks.

Many plutonic bodies are extremely irregular in shape and can hardly be included in any classification, but, speaking in a very general sort of way, these bodies may be regarded as modifications and combinations of two fundamental types.

The first of these types is the *dike*, which, as its name implies, is the filling up of a fissure with molten rock, a fissure which cuts across the bedding or stratification planes of the intruded or country rock. Like the fissures which form fault planes, those that are occupied by dikes are generally not vertical, but more or less inclined. When the intrusive rock has solidified and is exposed by denudation, the dike commonly stands up like a wall, because harder and more resistant than the country rock; but there is a limit to its height, which, to a very large extent, is determined by its thickness and the degree of its inclination. There is no general rule of thickness, which may be measurable in inches or in yards, and the length may be many miles. The thicker a dike and the less inclined from the vertical, the higher it can be and remain self-supporting; but dikes are seldom seen more than forty or fifty feet in height, and in a great many instances they do not project above the surface at all, because they are thin and easily disrupted, especially by frost.

In some regions there are great numbers of dikes, which fall into systems of parallel fissures, just as do the lines of faulting, and the various systems intersect one another at all sorts of angles. The plateau of northwestern Wyoming, lying to the east of the Yellowstone Park, is such a region; and when one stands high up on the slopes of the Absaroka

Mountains and gains a wide view over the country, it appears to be divided into a great number of immense fields, of every conceivable size and shape, which are inclosed by intersecting stone walls. These walls are dikes, left standing in relief by the denudation which has worn away the country rock. It will be noted that, as topographical features standing out in relief, dikes are most frequent in dry climates. The sandstone belt which occupies the Connecticut Valley and, after the interruption of Westchester County and Manhattan Island, New York, reappears on the west shore of the Hudson and crosses New Jersey, Pennsylvania, and Maryland unbrokenly, is everywhere accompanied by masses of igneous rock, both volcanic and plutonic, which are conspicuous features in the landscape, but dikes are not among them. Not that dikes are absent from the rock masses; in many localities they are seen in cross section, included in the sheltering country rock, but they do not stand out in relief, as they would do if they were thick enough.

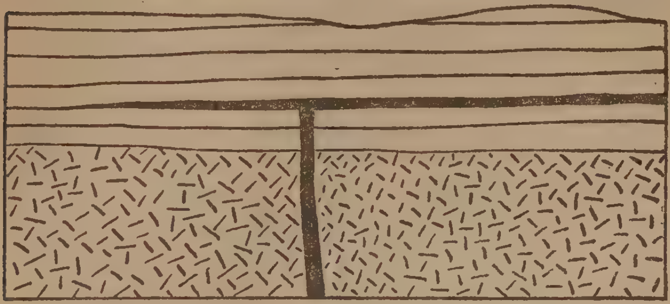


DIAGRAM OF DIKE RISING THROUGH IGNEOUS AND SEDIMENTARY ROCK AND SPREADING INTO A SILL BETWEEN THE BEDS OF THE SEDIMENTARY ROCK

Usually, the country rock traversed by a dike is sedimentary or metamorphic, but sometimes an older plutonic body is cut by dikes of a rock which is of later date of intrusion. On the Maine coast the granite is seamed with dikes of another rock, so conspicuously different in color that the contrast is marked, though there is no difference in relief.

The second class of plutonic bodies is exemplified by the *sill*, or intrusive sheet. While the dike cuts across the planes of stratification, the sill conforms to them, forcing its way between strata and lifting the overlying mass. Of course, the sill must have been fed from below by dikes, or perhaps cylindrical pipes, which broke across the strata from some deep-seated subterranean reservoir far below the limits of observation. Then, too, a sill will itself break across the bedding planes from one level to another, but is, in the main, concordant with the stratification, everywhere taking the line of least resistance, wherever that may lead. In thickness, there is every gradation from a mere vein to a huge mass. A magnificent illustration of the sill is afforded by the Palisades of the Hudson, which for more than thirty miles form the towering west bank of the river, an abrupt wall of such imposing dimensions that it has long been famous. At Weehawken and other places may be seen, near the river bank, the contact with the underlying sandstone and on the summit of the cliffs patches of the original sandstone covering remain, though, for the most part, this covering has been stripped away by denudation. Westward, the great mass inclines gently until it passes out of sight beneath the mass of sandstones which crosses New Jersey. The abrupt river face is believed to be a fault scarp and, if so, there must be a line of fault in the river bed, but, since the evidence of this fault is chiefly concealed under water, it is difficult to make sure of it. The southern edge of the great sill forms Rocky Hill, a low ridge of trap which extends from Monmouth Junction, on the Pennsylvania Railroad, to the Delaware River. Well borings and other deep excavations have shown that the sill is continuous between the two exposures, and hence it is called the Palisades—Rocky Hill Sill in the official reports. Sills are usually composed of the kind of igneous rock material which melts at a relatively low temperature and becomes very perfectly fluid. When the rock is of the sort that remains pasty and viscous, the plutonic body is unable to work its way between strata for any great distance and pushes the overlying strata up into a dome and takes on a mushroomlike form itself. This very peculiar form of plutonic rock was first observed in the Henry Mountains of southern Utah, a group of domes which rises abruptly from the plain and shows no linear arrangement. They are in all stages of dissection and degradation, so that the form of the plutonic mass and its relation to the underlying and overarching strata of sedimentary rock can be fully determined. There is another remarkable group of such hills northeast of the Black Hills in South Dakota; they, too, are scattered about, without obvious arrangement, and display various stages of dissection, from those in which the cover of stratified rock is still intact, to those in which the covering has been entirely removed by denudation and only the core of the plutonic body remains. Since their first discovery and naming (*laccoliths*) in the Henry Mountains, by Mr. Gilbert, of the U. S. Geological Survey, they have been identified in many other regions.

Still another form assumed by the plutonic bodies is the *stock*, a conical mass which enlarges downward to its junction with the parent mass from which it was given off. It differs from the sill and its modifications by cutting across the strata of country rock and not in lifting or doming them. Indeed, it is an unanswered question as to what has become of the strata which once occupied the space now filled by the stock and the even larger plutonic masses. In some instances the country rock has plainly been pushed aside and crumpled or shattered around the edges of the intrusive bodies, in other cases the intrusive mass cuts cleanly through the bedding planes. Stocks give rise to rudely conical hills as they are exposed by denudation, for they are usually more resistant than the inclosing country rock, and the deeper erosion is carried, the more the hill stands above the surrounding plain. Sometimes, however, the country rock prevails and the stock, when once exposed, weathers faster than the country rock and thus gives rise to a dishlike depression, instead of a prominence. Snake Hill, which rises steeply in the Newark Meadows, behind the Palisades and near the western portal of the Pennsylvania tunnel, is an example of a stock which, in all probability, widens downward to its junction with the great sill.

Finally may be mentioned the great masses of igneous rock which extend uninterruptedly for hundreds, or even thousands, of miles. Many mountain ranges have a core of granite which forms the heart of the mountain mass, with the folded stratified rocks arching over it. When the covering of strata has been removed by denudation, the highest part of the range is then formed by the exposed granite, which speedily forms a very rugged topography of sharp peaks and serrate ridges. The Rocky Mountains and Sierra Nevada have granite cores for their whole length, which, like the ranges themselves, are relatively long and narrow. The highest peaks in California and Colorado are in the granite, but here and there one can find remnants of the cover of stratified rock which once arched continuously over the granite. In saying that the granite cores of these ranges are long and narrow, it is meant that their visible and ascertainable portions have this character; what their deep-seated extensions may be, no means of determining has yet been devised to show. The crystalline core of the Black Hills has the elongate oval shape of that uplift, but there are other huge plutonic masses like many in New England and especially in Canada, which have no definable shape and no one axis very greatly exceeds the others in length.

This by no means exhausts the list of particular shapes assumed by the plutonic bodies, but it would serve no good purpose to enumerate them all. Whatever their shape, they generally form prominences of the surface, when laid bare by denudation, because, as a rule, they are harder and more resistant than the country rock which they have invaded. In the sandstone belt already referred to, the plutonic masses form many of the most familiar landmarks of the Connecticut Valley and central New Jersey; Mount Tom and Mount Holyoke, East and West Rock, near New Haven, the Palisades, Snake Hill, Orange Mountain, the Watchung Mountains, near Paterson, N. J., Rocky Hill, the Sourland Mountains, are all of this description, though in a very subordinate way volcanic bodies cooperate to form these topographical features. Both in New Jersey and in New England, some of the "trap rocks" are distinctly volcanic, and there are accumulations of the fragments blown out of volcanic vents by internal explosion. Denudation has removed most of the volcanic rocks in cutting down the surface so as to expose the plutonic masses beneath.

The intrusion of these highly heated, molten masses into the sandstones and shales of the belt has caused the metamorphism of the intruded rocks, though the effect does not extend far from the contact zone between the sedimentary strata and the igneous masses. It very frequently happens that valuable bodies of metallic ores are developed in the contact zone, and, in Colonial days, copper was quite extensively mined in New Jersey, and the ores were shipped to Wales for smelting, but the miners of those days would seem to have exhausted the mines.

The examples of topography caused by the laying bare of masses of plutonic rock mentioned in the foregoing lines have almost all been taken from a region near New York, but they are found the world over. The form of the plutonic body is the shape it takes when denudation lays it bare. Some of these features, like Arthur's Seat near Edinburgh, in Scotland, and the peak of Corcovado at Rio de Janeiro, are of great celebrity.

Attention has repeatedly been called to the fact that sometimes the plutonic rocks are less resistant and weather more rapidly than the country rock and, in that case, such rock masses give rise to depressions instead of projections. An example of this is seen not infrequently in North Carolina, where the trap dikes are marked by trenches, with an accumulation of clay at the bottom, caused by the weathering and decomposition of the plutonic rock, while the country rock inclosing the dike has suffered very much less. Railroad cuttings have brought several instances of this to light, and similar phenomena have been observed in many other regions, especially in warm climates.

In *Metamorphic Rocks* the land forms follow the same rules as those which control the preceding classes. It is true that, topographically, metamorphic rocks do display certain characteristic differences from the sedimentary and igneous classes, but, for the most part, those differences affect small details and need not be considered at present.

For all classes of rocks the general principle may be laid down that, in a region of mature topography in which there has been time for all the denuding agents to make themselves fully felt and for all the various rock masses to have exerted their characteristic influences, the arrangement of the rocks is the controlling factor in determining the character of the land forms. The harder and more resistant rocks, to whatever class they may belong, form the prominences, ridges, hills, mesa tops, and the like, and the softer rocks mark the course of the valleys and depressions. It should be noted, however, that a thin capping of hard rock may for a considerable time protect an underlying mass of softer rock and so cause it to be equivalent to a hard mass. This is but a temporary effect; sooner or later undermining will dispose of the hard cap.

CHAPTER IV

THE TOPOGRAPHICAL EFFECT OF FAULTS AND JOINTS

IT may be well to remind the reader that a fault (p. 37) is a fracture of the rocks, accompanied by a dislocation, the mass on the upthrow side being pushed up and on the downthrow side dropped down. It is often quite impossible to say what was the actual direction of the movement; it is the *relative* movement of the rocks on the two sides of the fracture that is registered by the fault. We may also repeat here the highly important fact that faults are seldom vertical, but are almost always steeply inclined. In a normal or gravity fault the inclination or slope (i. e. following it down) is toward the downthrow side, as though that side had merely settled down along the fault plane, and, no doubt, that was what actually took place in many instances. In a reversed fault the slope is toward the upthrow side, as though that side had been pushed up along the fault plane, and, again, that probably happened often. Of modern instances, in which faults have been observed immediately after their formation, there are many, some of which have already been referred to, such as those in Yakutat Bay in Alaska, with a movement or "throw" of forty-seven feet. A long list of these modern examples of faulting might be compiled, but, if the reader will remember that faulting is no uncommon thing to-day, every purpose of such a list will be served. It will be noted that these recent examples of faulting are almost always associated with great earthquakes, and one might be tempted to infer that the fault has been produced by the earthquake. That would be putting the cart to draw the horse; it is more likely that faulting caused the earthquake

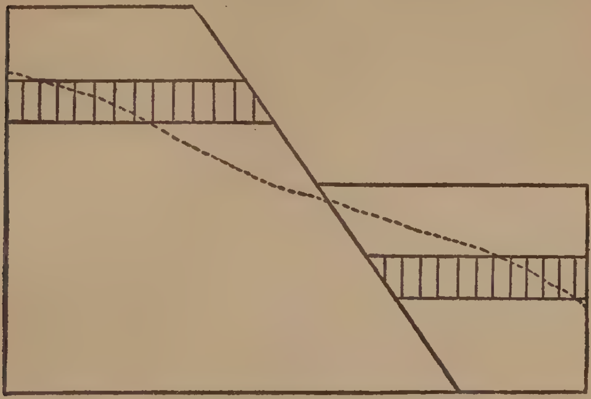


DIAGRAM OF SIMPLE GRAVITY FAULT SEEN IN TWO-DIMENSIONAL CROSS SECTION

Broken line shows surface produced by denudation since the fault. Upthrow side on the left, downthrow on the right

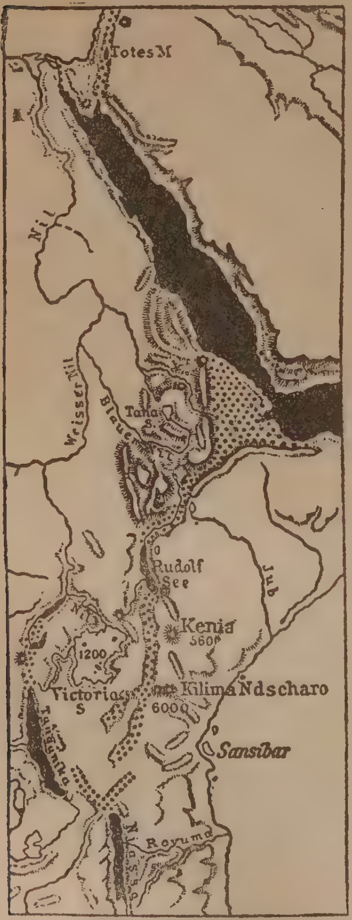
than *vice versa*, and still more likely that both are effects of the same cause.

Faulting, as we have learned, results in the formation of a scarp (or escarpment), a line of cliffs, or bluffs, or banks, the height of which is determined by the amount of the dislocation, or throw. In the case of geologically ancient faults, in regions of abundant rainfall, the scarp has generally been removed by the action of the denuding agents and the upthrow side planed down to the level of the downthrow, or, if not actually to its level, the upthrow and downthrow sides are worn into a continuous slope, which shows no visible break or interruption. Many a hillside that seems to have been cut out of a continuous, unfractured body of strata, is really traversed by a great fault, but no surface feature is left to mark it and the fissure itself is deeply buried under a thick soil. So immensely important are faults to the practical mining engineer, as well as to the geologist, the accuracy of whose maps is altogether dependent upon the detection of faults, that methods have been devised to find and accurately locate these hidden dislocations, but topographically, they have ceased to have any effect. This removal of the fault scarp by denudation has by no means invariably happened, and even in regions of heavy rainfall and severe frosts faults of very high geological antiquity may continue to dominate and control the topography.

As a rule, faults do not occur singly, but in multiples, which are arranged in more or less complex, but quite definite, systems, parallel, branching, intersecting. The topographical forms resulting from these multiple or compound faults are, in the first instance, determined by the throws, or amounts of the various dislocations and, secondly, by the relations of their slopes or inclinations to one another. A series of parallel faults, which all incline in the same direction, gives rise to a gigantic staircase; hence these are called step faults. Each step, supposing the inclination of the faults to be toward the east, is on the downthrow side of the fault on its western side and the upthrow side of the fault on its eastern. Each step is a fault block and its top may be horizontal or tilted. If two parallel faults slope away from each other, the block between them is on the upthrow side of each fault and so stands as a "block mountain," if sufficiently high. The Vosges Mountains and the Black Forest, which face each other across the broad and deep Rhine Valley, are examples of this. Another is a block 3,600 feet high above the African plateau, on which it stands, and more than 7,000 feet above the sea. Block mountains may also be formed by the strong tilting of one of the steps in a series of step faults, which is the explanation usually given of the Basin Ranges, short north and south mountain ridges which parallel one another in Nevada and Utah. The Great Basin is bounded on the west by the great fault scarp of the Sierra Nevada, which has an eastward inclination, and, 800 miles away, on the east by the fault scarp of the Wasatch Mountains, which inclines westward. The floor of the basin is broken by many faults, mostly in north-south direction and descending by a series of tilted steps from the Sierra on the west and the Wasatch on the east.

If the parallel faults incline toward each other, the block included between them is on the downthrow side with reference to both faults and a great trough or rift is the result. The Rhine Valley, for the middle of its course, is of this description and if our imaginary east and west trench across France (see p. 88) be continued across the Rhine, it would show that river flowing in a channel cut in its own deposits, which have deeply buried the rocky floor of a rift valley.

Incomparably the most striking and remarkable instance of fault-controlled topography is the Great Rift Valley of Africa, of which the depression of the Red Sea, the Gulf of Akabah, and the valley of the Dead Sea and the Jordan are believed to be the northern extension; if so, the great rift exceeds 4000 miles in length and is one of the most wonderful features of existing topography. Whether or not the Red Sea is properly included in this system, there can be no doubt of its occurrence on an immense scale in eastern Africa and on a somewhat smaller scale in Syria. The great valley has been described by many travelers, and the following passages from J. W. Gregory's "Great Rift Valley" will give some conception of its character. "A wonderful prospect burst upon us. We were on the face of a cliff 1,400 feet in height, broken only by a platform 500 feet above the floor of the valley. From the foot of the cliff a level plain extends thirty miles to the west, to the foot of the scarp at 'Mau.' * * * Far to the west



THE GREAT RIFT VALLEY OF E. AFRICA

The dotted areas are the dry portions and the black areas the water-filled part of the valley. (*After Supan.*)

we could see the long, dull gray scarp of the plateau, which forms the western boundary of the valley * * * The valleys we had previously seen were constructed on the same plan as those of England; for their curves were sinuous and their slopes rounded, since they were made by the familiar processes of denudation and erosion. But, on emerging from the Kikuyu forests, we entered one which was straight in direction, and was bounded by parallel and almost vertical sides; its characteristic features were that its lines were straight, and that its angles retained some of their original sharpness, for the direct action of faults and earth movements still dominated the scenery. An hour after entering this valley, we reached the edge of the Great Rift Valley, which, like the former, must be directly due to earth movements. Once the plateaus of Mau and Kikuyu were continuous across the site of the Great Rift Valley; a double series of north and south [faults] cut through the plateau and allowed the block of material between them to subside. This left a great open Rift Valley. * * * Strips of country have fallen owing to a series of parallel cracks or 'faults' and thus a valley has been formed with precipitous, and sometimes steplike sides. Such valleys have long been known in America." It is evident that in Africa "great earth movements have happened so recently that rock scarps, 1,000 to 2,000 feet in height, still stand bare and precipitous as though formed but yesterday, and straight lines and sharp angles still dominate the scenery. The recent date of such earth movements has therefore rendered the physical features of the country such a direct expression of its geological structure, that this can be recognized in a hasty traverse." The floor of the valley is very uneven and contains no less than thirty lakes, besides alluvial deposits and beach lines made by lakes that have disappeared in the growing desiccation of the climate. Volcanoes were established on the floor of the rift and poured out floods of lava. No doubt, too, there were great inequalities of depression and settling, and many cross ridges have been subsequently formed. The southern portion of the valley bifurcates and incloses a large area of the plateau between its two arms, on which is the large Victoria Nyanza lake. There is a notable difference in form between this and the lakes which are in the valley; the Victoria Nyanza is not only a very large lake, but is rounded in outline and has low shores, gradually sloping down beneath the water, while the lakes in the Rift Valley are almost all narrow and elongate and, with one exception, have no outlet to the sea. The main stream of the Nile is the outlet of the Victoria Nyanza and flows into the Albert Nyanza, which is in the valley. A northwesterly branch of the Rift Valley, which is regarded as being of later formation than the other parts, opened a way of escape for the Nile and enabled it to reach the Mediterranean. The remarkable distribution of the fresh-water fishes, and of other groups of animals and plants, would seem to require a fresh-water connection between the Jordan and the East African streams, a connection from which the Nile was excluded.

In Syria the Rift Valley, there known as the Ghor, is as striking as it is in Africa; its northern end is not far from Damascus and it forms the whole length of the Jordan Valley and that of the Dead

Sea. For much of its length the Ghor is below sea level, the Sea of Galilee is more than 600 feet below the Mediterranean, and the Dead Sea nearly 1,300 feet. South of the latter, the valley gradually rises to the sea level at the north end of the Gulf of Akabah, the northeastern branch of the Red Sea. The gulf is manifestly a continuation of the Ghor, which passes beneath its waters. The Ghor has precipitous sides, the fault scarp on both sides being almost intact, though gashed with deep water courses. On the western side, the Wilderness of Judæa, an extremely arid district, is on a shelf, where a step fault has let down a slice of the plateau. Though difficult, it is not impossible to cross the valley, and a road has been built with a bridge over the Jordan; but the great valley, with its cliffs, has been from immemorial times a strong defense against the marauding tribes which wandered in the deserts east of the river. The history of the Jewish people would have been altogether different had it not been for this great natural moat which protected them on the east. It was from this point of view that Humboldt declared the great valley to be incomparably the most important of geological phenomena. In Africa the valley played no such rôle, for its course there is through unredeemed barbarism; there was no civilization to protect, but, from the purely geological standpoint, the Great Rift Valley is one of the most extraordinary features of the modern world.

While the list of examples where the topography is due to geologically recent faulting might be greatly extended, it is unnecessary, as no additional principles would be illustrated. Whether the topographical forms due to faulting are to persist for any long periods of time, or to be speedily removed by the denuding agents, is determined by the relative hardness of the rocks on the upthrow and downthrow sides. There is also the difference in climatic efficiency to be taken into account, fault scarps, like other features of relief, persisting longer in arid climates. If the rocks on the upthrow side, or those which are brought to the surface on that side by the movement of dislocation, are notably harder than the rocks exposed on the downthrow side, the fault scarp may persist for ages, whatever modification of its originally simple form may be caused by destructive weathering. If the Palisades of the Hudson be correctly interpreted as a fault scarp, we have then an instance of great hardness and resistance on the upthrow side, with an extremely small amount of change through denudation. The eastern face of the Sierra Nevada range is formed by the upthrow of a gigantic fault; its rocks are harder than those of the downthrow side at its foot and the great, simple scarp, which the fault originally made, has been carved into exceedingly complex forms by the weather, the stream, and the glacier. The strata of sedimentary rock which once covered the granite core have, for the most part, been stripped away and the granite itself deeply gashed so as to form deep valleys, knife-edge crests, broad, serrate ridges and peaks. Sculptured in this manner, the fact that the great mountain wall is a fault scarp is not immediately obvious, and across the Great Basin, the westward face of the Wasatch Mountains, also a fault scarp, has been sculptured in much the same fashion.

Another instance of similar sort is afforded by the Highlands of Scotland, which are composed of very ancient and very hard rocks, brought up from great depths on the upthrow side of a fault, which crosses the country from sea to sea. The Lowlands, which are on the downthrow side, are composed of softer and more destructible rocks and therefore the difference in elevation between the two sides, upthrow and downthrow, has persisted despite the great antiquity of the movement. In the long ages during which the Highlands have been exposed to the destructive agencies they have been very extensively modified and the scarp has been carved into a very rugged face, disguising its essential nature, but the difference in level between upthrow and downthrow has persisted nevertheless. The southern part of Scotland, south of the Lowlands, is a subordinate upland or highland, which again forms the upthrow side of a fault, exposing more resistant rocks than those of the downthrow. The Scotch Lowlands are thus another rift valley, although the breadth is so great in comparison with the length that the term valley seems hardly appropriate. The structure is the same as in the Great African Rift and the Ghor of Syria, but very much more ancient, geologically speaking.

Trough, or rift, valleys are much more common than has, until quite lately, been supposed. In Europe, beside the middle course of the Rhine previously referred to, rift valleys are occupied by Lake Garda in northern Italy, the Christiania Fiord in Norway, the Gulf of Patras and Strait of Corinth in Greece. There are many examples of such valleys in Mongolia and southern Siberia, and Lake Baikal lies in a rift valley. Notwithstanding these, and many other cases that might be cited, streams, in the vast majority of instances, excavate the valleys in which they flow. The *location* of the lines along which these valleys are to be cut has frequently been determined by other agencies.

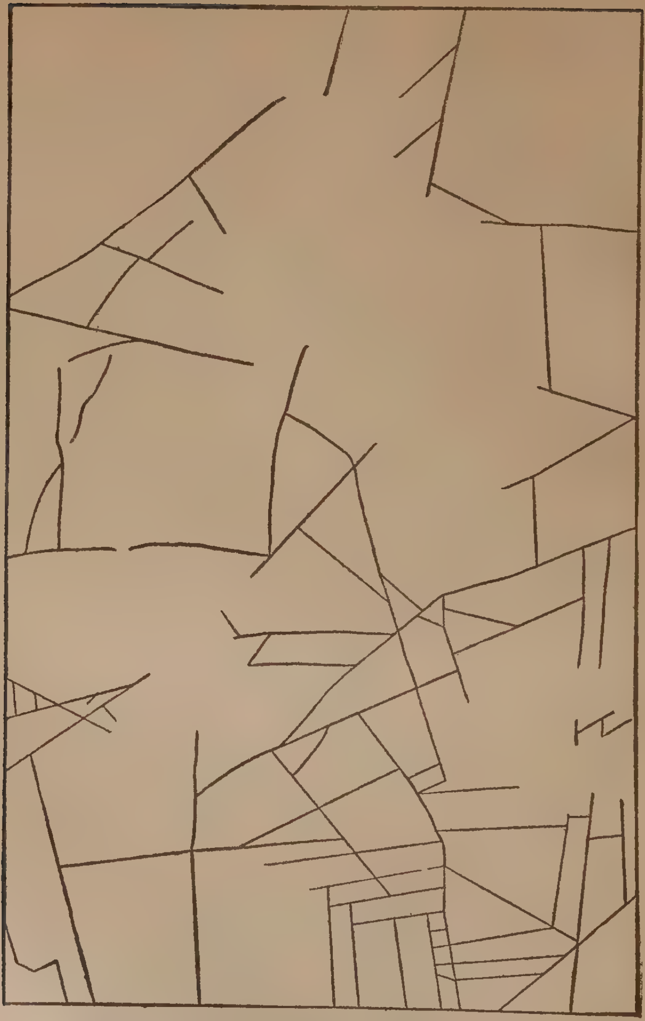
All over the world similar features of relief through faulting are to be found, either where erosion is extremely slow, as in arid regions, or where the upthrow side of the fault consists of the more resistant rocks. A section across the great plateau of northern Arizona and southern Utah, through which the Grand Cañon of the Colorado has been cut, shows that on the eastern side the high plateau descends to a lower one by a flexure of the rocks. On the west side is a great fault scarp, known as the Hurricane Cliffs, where the surface abruptly drops for several thousand feet. The endurance of these cliffs, with only minor sinuosities due to the downcutting of streams and the sapping, undermining action of springs, is occasioned not so much by the hardness of the rocks as by the aridity of the climate. Along the western flanks of the Wasatch Mountains in Utah are standing fault scarps in loose gravel, which, even in that very dry climate, must be of very recent date; that they should persist at all can be possible only in arid conditions.

The topography of eastern Asia is controlled by gigantic systems of faults. The mountain ranges which form the western boundaries of the coastal plains follow a zigzag course, but their general trend is roughly parallel with the coast. These ranges mark a series of great faults with downthrow to the east. The coastal plain itself is cut by a series of parallel step faults into fault blocks, also with downthrow to the east, forming a series of terraces. The terraces have tops inclining westward, because the fault blocks are tilted in that direction.

An east and west section through northern China displays three such enormous fault blocks. On the west is the Mongolian block, then follows the Manchurian block, and on the east is the partly submerged Japanese block. The westward tilting of the blocks causes the easternmost one to emerge on its eastern side, which forms Japan, while its western side passes below sea level and is flooded. The whole chain of islands which fringes the east coast of Asia, and may be followed through sixty degrees of latitude to the Arctic Circle, is carved from the edge of a tilted fault block.

Not only are the great outlines of topography in eastern Asia determined by systems of gigantic faults, but many minor features also of similar origin. The features of the Korean peninsula are the product of intersecting faults, of which the principal series extends from northwest to southeast. The whole country has been compared to a chessboard of fault blocks. Japan has been divided into two parts by a great transverse fault; north of this, the island has a general north and south direction and is controlled by fault lines; south of it, the island turns to the west and is determined by the axes of folds.

In the long run, in a topography due to faulting, as in all other classes of topography, it is the relative hardness of the rocks which is the controlling factor that persists longest in the relief of the land. Folding and faulting are of enormous topographic importance, but the effect which the denuding agents produce upon folded or faulted surfaces is a question of rock resistance. The effect of earth



FAULT COMPLEX, TONOPAH DISTRICT, NEVADA

Showing the mosaic of blocks made by intersecting faults.
(*After Spurr*)

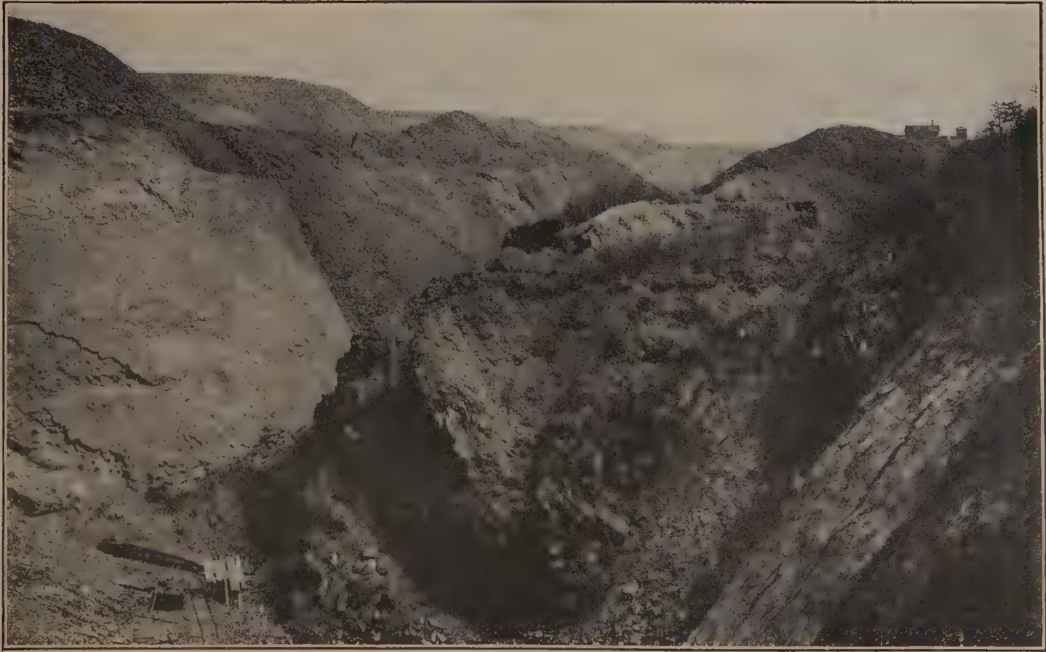
movements may persist throughout whole geological ages, of unimaginable duration, but it does so because of the arrangement of hard and soft rocks which the movements bring into play. We saw that denudation may actually reverse the topography of a folded region, cutting out the new valleys along the uplifted saddles and retaining the bottoms of the original valleys of folding as the tops of the new ridges. In similar fashion, the topography of faulting may be reversed; if the rocks of the downthrow side be much more resistant than those of the upthrow, the fault scarp will first be cut away, equalizing the level of the two sides, and then a continuation of the denuding process will cut the upthrow side below the level of the harder downthrow, which will form a new scarp. Ultimately, of course, all the irregularities are swept away, provided the cycle of geographical development be not broken off by a renewed elevation of the country and a consequent rejuvenation of the denuding agents.

Faults frequently produce topographical effects indirectly. For example, faulting has often determined the position of valleys, not because of difference of level between upthrow and downthrow sides, but because the faulting has produced a belt of shattered rocks which can be cut away with comparative ease, and a line of depression in which a stream readily formed. These are additional to the valleys directly due to trough-faulting, the rift valleys made by the sinking of a fault block between two parallel lines of scarp, and are made by a stream or a series of streams which find the fault the line of least resistance. Fault valleys are very common in the Sierra Nevada Mountains and in the Great Basin which lies to the east of them. In the Coast Range of

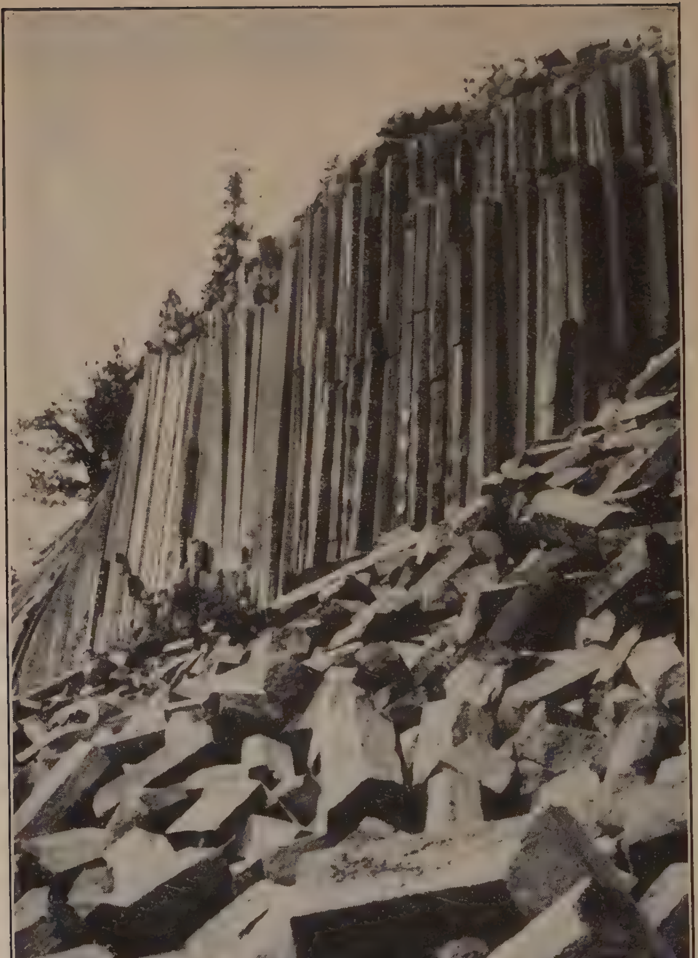
California a series of valleys, more than 400 miles long when taken together, have been excavated along a fault line. There is much reason to believe that the San Francisco earthquake of 1906 was caused by a renewal of the movement along this fault plane, as the many small earthquakes, which are so frequently felt in southern Germany, are traceable to a line of fault along the northern edge of the Black Forest. In the Adirondack Mountains, the streams follow fault lines so generally that, when seen on a good map, the regularity of the system is extremely striking and has called forth the term "lattice drainage." In the eastern Adirondacks is the impressive cañon of the Ausable Chasm, a gorge so youthful that it retains the perpendicularity of its sides. For part of its length, the chasm was predetermined by lines of fault.

THE INFLUENCE OF JOINTS

All rocks, other than loose, uncompacted masses like gravel, sand, or clay (all of which are called rocks by the geologist) are divided into blocks of greater or less size by fissures known as *joints*, a term which was invented by quarrymen before a science of geology was thought of. The great practical importance of joints was recognized and the necessity of having some name for them was obvious. The art of quarrying consists in taking advantage of the systems of joints, so as greatly to facilitate the removal of the rock with a minimum of labor and without shattering the stones to pieces by indiscriminate blasting. The quarry is so worked that both face and end of the block are accessible. Sometimes the blocks are of great size, such as can be employed for the monolithic columns of



COAL IN PLACE AT THE BOTTOM OF A SYNCLINAL TROUGH. It is an open stripping of the Pardee Company near Hazleton, Pennsylvania, and the coal has been stripped off the smooth walls to the left and right. In the middle is sedimentary material above the coal



THE DEVIL'S POST PILE. This is a remarkable formation of basaltic columns situated in the Sierra National Forest, California. Most of the columns are hexagonal, with an average diameter of about two feet marble or granite; sometimes they are very small, and then the stone is of no value for building purposes. Much of that value is conditioned by the size and shape of the blocks.

Joints occur in three dimensions, so that their intersection completely isolates the block. Rock masses are thus invariably and without exception masses of separate and larger or smaller blocks, a fact which greatly facilitates the attack of the denuding agencies upon them, allowing water to pass through the thickest rock masses and frost to loosen and shatter the joint blocks. Igneous rocks, like a lava sheet or a mass of granite, are jointed, as well as sedimentary rocks, such as sandstone or limestone. In the igneous rocks, joints are manifestly shrinkage cracks, caused by the contraction of the hot mass, as it first solidifies from the molten condition and then slowly cools. In masses of such size and weight shrinkage without rupture would be impossible, and so the ruptures occur along the lines of least resistance. In igneous rocks, both volcanic and plutonic, that are very homogeneous, especially in fine-grained basaltic lavas, a highly remarkable and characteristic form of jointing occurs, the hexagonal columns that have aroused wonder in so many lands. Certain localities, such as the Giant's Causeway in the north of Ireland, Fingal's Cave in the island of Staffa, off the western coast of Scotland, places on the Rhine, in Mexico, in Hawaii, in the Yellowstone National Park, have long been famous for the extraordinary character of their jointed rocks, which consist of hexagonal columns that have a highly artificial look. Mato Tepee (sometimes and unfortunately called the "Devil's Tower"), a most impressive tower-shaped, plutonic mass, which springs 700 feet into the air from the plain northeast of the Black Hills in South Dakota, is beatifully jointed.

The columns have their long diameters at right angles to the cooling surfaces and, therefore, when they appear in sills the columns are vertical, and they are horizontal in dikes. If the cooling surfaces were curved or irregular, the columns follow the irregularity and some most remarkable forms have been produced. In Clam Shell Cove, on the island of Staffa, the columns accurately form the half of a keeled boat, seen in cross section.

The jointing of sedimentary rocks has been caused in a manner that is not at all well understood, but is most probably to be explained as the cracking of the rocks when subjected to twisting stresses by earth movements, small or great. However they may be caused, they are invariably present in all consolidated rocks of the sedimentary class. There is a tendency for each kind of rock to have its characteristic form of joint block, differing in size and shape from those of other rocks; but, inasmuch as the jointing of sedimentary rocks is largely conditioned, if not altogether caused, by earth movements, there is much variety in this respect in rocks of the same general character.

Joints are extremely important in determining the details of topography and drainage, because they are lines of weakness through which the water penetrates, and frost and undermining springs effect so much destruction. Master joints (again to use a quarryman's phrase) which run through several strata and continue for long distances, should probably be regarded as minute, incipient faults, for ordinary joints do not extend beyond the limits of a single bed. Undermining, or sapping, is a very important method of cutting back hard rocks, which are underlaid by softer and weaker beds. The support of the hard bed is gradually removed and it projects until it can no longer support its own weight and the overhanging part falls. The yielding is along the joint faces and so the cliff front remains vertical, though, when the beds are steeply inclined, the joints, which are at right angles to the bedding planes, will produce a cliff which is inclined in the opposite direction.

Another important effect which is due to joints is the location of the minor drainage lines of a district. Wherever this matter has been studied with care and accuracy, as has been done in parts of France, in Connecticut and Wisconsin, it is found that the network of small streams coincides very closely with, and is manifestly guided by, the scheme of rock-jointing in that district; the master joints, which have a uniform trend for long distances, are particularly effective in fixing the drainage lines. The Ausable Chasm of the eastern Adirondacks, referred to above as being a gorge partly made by a fault, actually pursues a zigzag course, in part along a fault plane and in part along a line of master joint. One of the most remarkable cases where the course of a large river has been determined by jointing is that of the Zambezi in southeastern Africa, the deep gorge of which is cut through the thick mass of a lava plateau, such as was described for the Columbia River region of the northwestern United States, and eastern equatorial Africa, near the Great Rift Valley. In every way the gorge of the Zambezi is an unusual example of river erosion. Above the marvelous Victoria Falls the river is more than a mile wide and, at the great cataract, plunges down nearly 400 feet into a narrow chasm which runs *across* the course of the stream. From this great transverse gash in the plateau the only outlet is a narrow gateway of fifty or sixty yards in width, through which the river rushes with great velocity, and for the remainder of its course through the lava plateau the gorge is very narrow and continues for miles in a series of sharp zigzags. The limbs of these zigzags are almost at right angles to one another, and the whole arrangement is most exceptional in so hard a rock as a basaltic lava which has been trenched to a depth of nearly 400 feet. The course of the gorge has been determined by the master joints, the river attempting, as it were, to maintain a southerly course, but being repeatedly deflected along joint-planes. The great transverse chasm into which the cataract plunges is cut out along a line of fault, where the rock yielded more readily, and this fault may be traced in the cliff at either end of the chasm. The cataract is not continuous for the whole width of the river, but is divided into several parts by islands on the brink of the chasm and, at the present time, the westernmost fall, which is known as Leaping Water, has discovered another line of weakness and has cut its bed fifteen feet below the level of the other falls and is manifestly beginning the formation of a new zigzag. No determination of the rate of recession of the falls has yet been made, nor has it been shown why the falls continue to maintain a vertical face. Waterfalls in homogeneous masses of rock usually retreat most rapidly at the top, so that the fall is no longer vertical. but forms a series of steps, as in the Falls of the Rhine at Schaffhausen. The verticality of Niagara is plainly due to undermining.

Sandstones, and especially limestones, are usually so regularly jointed that a cliff of old and long-weathered rock looks like a mass of ancient masonry. Granite, likewise, is often divided by three sets of nearly rectangular joints, widely spaced, so as to include very large rectangular blocks. When thus jointed, granite cliffs also look like old walls of masonry and rise in steplike terraces. Other granites have only the vertical joints very strongly developed, and then craggy cliffs and needlelike summits result from weathering. The Palisades trap, as displayed in Bergen Cut, where the old line of the Pennsylvania Railroad enters Jersey City, is most irregularly jointed, blocks of all shapes and sizes occurring mingled with great sheetlike slabs in utter confusion. Though the blocks are chiefly rectangular, they weather into rounded bowlders, as so very frequently happens with rectangular blocks, because the corners, attacked on all sides at once by the destructive agents, are the first to wear away and thus form rudely spheroidal bowlders out of rectangular blocks, a process which may be observed in actual operation in many quarries.

The highly metamorphic rocks, such as schists and gneisses, are usually very irregularly jointed and so give rise to extremely rugged surfaces, and mountains composed of such rocks may be readily recognized at considerable distances. Under given climatic conditions, each kind of rock weathers in a characteristic way, determined by the hardness or softness of the rock, and then by the joints and the consequent size and shape of the joint blocks.

CHAPTER V

THE GROUND WATER

OF all the natural processes that are in constant operation, none is so vitally important to all forms of living things as the circulation of water. The sun's heat causes continual evaporation from the surface of the sea, and the vapor thus produced is borne over the lands by the winds; under suitable conditions the vapor is condensed and precipitated as rain or snow and is then returned to the sea by rivers and springs. By some highly competent authorities, however, the system of circulating waters is not believed to be quite so simple as this statement would imply. Thus, Supan says: "The circulation of water is not complete. Part is withdrawn for a long time, perhaps permanently, by the conversion of anhydrous into hydrated minerals. Our planet would eventually become completely desiccated, if there were not a supplementary supply derived from its interior, a supply, however, which will not be of unending duration."

Disregarding for the present this supplementary source of water, we may say that all the water on the land, in the form of lakes, streams, etc., all the snow of high mountains and the ice of glaciers, and all the water beneath the land, are derived from atmospheric precipitation. Of this precipitated rain or snow, part flows off the surface into the nearest watercourse, part is immediately returned to the atmosphere by evaporation, and part sinks into the ground. If the fall of rain and snow were spread equally over the entire land surface of the earth, it would be rather more than three feet annually, which would amount to about 35,000 cubic miles of water. It is estimated that the annual discharge of the rivers into the sea is about 6,500 cubic miles of water, so that rather less than one-fifth of the total precipitation on the land is returned to the sea by the rivers. Of course, in the present state of knowledge, no exact statement concerning the annual total discharge of all the rivers of the earth can be made, but the estimate given above approximates the truth. Evaporation accounts for a large part of the deficit; even in moist regions evaporation is large and in some lands of very heavy rainfall, such as Central America, evaporation is so great that the rivers are comparatively small, much smaller than would be anticipated from such precipitation. In the closed basins which have no outlet, evaporation disposes of almost all the precipitation, whether or not the streams end in salt lakes. Over the western part of the Great Plains, evaporation amounts to about five feet a year, nearly three times the precipitation. This statement sounds rather paradoxical, but it simply means that evaporation from the surface of a pond or reservoir equals sixty inches annually; needless to say, it is impossible that three times as much water should evaporate as falls.

That portion of the precipitated water which sinks into the ground is the *ground water*, which supplies wells and springs; part of it is returned to the surface by springs, part is known to seek the sea by subterranean channels, and part is retained beneath the land for hundreds or thousands of years as stagnant, or very slowly creeping water. The level below which the soil and the surface rocks are full of water is called the *water table,* or *water surface,* and its position is chiefly due to the rainfall, and partly also to the topography of the region. The water table fluctuates upward and downward with the amount of rain; when the snow is melting in spring, it may be very near the surface, and sink many feet below it in summer. In seasons of drought many wells go dry, because the water table has sunk below the well bottoms, others have proved unfailing, which is simply saying, in other words, that such wells have been put down to a depth beneath which the water table never sinks. Many springs likewise fail in prolonged droughts, because in them also the line of saturation, or water table, sinks below the mouth of the spring. When the rains return, the water table once more rises and the well or spring is again filled, usually, but not invariably, for it sometimes happens that the returning water seeks other channels and leaves the well or spring permanently dry. Earthquakes frequently produce the same effect of changing the position of the water table, with the result of drying up wells and springs and causing springs to break out in new places. Besides the rainfall, there is another factor which determines the position of the water table and its depth below the surface, and that factor is evaporation. The fluctuations of the water table and their annual period are determined by that factor which is subject to the greater annual fluctuations, which in some regions is rainfall, in others evaporation.

There is no kind of rock or soil which is altogether impervious to water, but those which contain a large proportion of clay are, when well wet and mixed with water, relatively impervious and permit water to pass through them but very slowly. Engineers take advantage of this peculiarity and employ well "puddled" clay to form a nearly water-tight bottom for a reservoir. When the relatively impervious bed forms the surface of the ground, springs are few or entirely lacking. If such a surface is flat, it becomes swampy. If it is inclined as a slope, water runs off it quickly, so that its streams are entirely dependent upon the immediate rainfall; if that is heavy, the streams are full and swift, but a brief period of drought suffices to dry them up.

Even the hardest rocks permit the penetration of water, because they are masses of blocks, separated by joint planes, and the separate blocks have microscopic pores and crevices which permit the penetration of water, and wells have been sunk in granite to a depth of a hundred feet, resulting in an abundant supply of most excellent water. Porous rocks, like gravel, sand, and many sandstones, are extremely permeable and allow water to descend until it is stopped by some relatively impervious bed, along which it spreads horizontally. When the irregular surface of the ground cuts such an impervious bed, overlaid by a porous one, a spring, or line of springs, is formed. These hillside springs, as they are called, because they occur on the slope of a hill or valley wall, often supply water of very good quality, but they are rather less trustworthy than judiciously placed and sufficiently deep wells, because they are more likely to go dry in periods of drought. Springs of another class are those which are placed along lines of deep fissure or dislocation in the rocks and are therefore called fissure springs. In them the water ascends through the fissure under the impulse of hydrostatic pressure, and such springs are usually abundant in flow and but little affected by casual droughts.

In a region like the coastal plain of New Jersey, which is built up of loose and unconsolidated marine strata and is but a sea bottom raised a little above tide level, the beds form an alternation of gravel, sand, and clay, and borings show several distinct water-bearing strata, each a porous sandy or gravelly bed, with an impervious bed of clay underneath. The water supply for the summer resorts along the New Jersey coast is derived principally from deep wells which penetrate the lower of these water-bearing strata, thus insuring water which is free from pollution. Artesian wells are, in fact, fissure springs artificially produced. A pipe is driven into the ground, the soil or rock within the pipe removed until a water-bearing bed, in which the water is under high pressure, is tapped. The water will then rise in the pipe and, if the pressure be sufficient, will form a flowing well, the water rising, it may be, like a fountain above the mouth of the well. In other instances, the water must be pumped because the pressure is insufficient to raise it to the well's mouth. Though underground water very often acts as though it were in a pipe, the source of a well or spring must be above its mouth, as is, of course, equally true of water flowing in pipes. It is not uncommon to find a spring on top of a hill, which may be the highest point in the area, but the source of the water may be a great many miles distant and is, of necessity, higher than the spring. The source of a spring or well means the area of the water-bearing bed, supplying the spring or well, which is exposed at the surface and upon which the rain water falls. The artesian wells of the James River Valley, North Dakota, mentioned elsewhere in connection with underground temperatures, are supplied from a porous sandstone, which crops out on the surface in the Black Hills, 400 miles away.

Underground water, like surface water, moves seaward, but, for long stretches, the two may move in diametrically opposite directions; both flow in accordance with gravity, but water on the surface flows in the direction of the slope, while underground water moves along the bedding planes and joints, the fissures and faults of the rocks. These subterranean structures of the rocks have no necessary connection with the surface slope, and it very frequently happens that the strata or beds slope downward into the hill, not with it. When houses are built on the brow of a hill and must provide for their own drainage and water supply, usually by means of cesspool and open well, the direction followed by underground water must be most carefully ascertained. If the well be dug at the top of the hill and the cesspool considerably down its slope, the arrangement would seem to insure the well against contamination by carrying all water toward the cesspool. When the beds of rock incline into the hill, such an arrangement might easily prove disastrous, for water from the cesspool, by following the bedding planes of the rock, would find entrance into the well. Such cases are not imaginary; they occur frequently enough in practice to make plain the necessity of caution. In thickly settled communities wells should be abandoned, as it is almost impossible to prevent contamination. If no other supply be obtainable, the water should always be boiled before drinking, a fact which the Chinese have learned and applied for thousands of years. Though not the only cause of epidemics, tainted water is the commonest means of spreading disease, and many towns which once were hotbeds of persistent typhoid fever have been made healthy by bringing in a supply of pure water.

The general problem of drainage and water supply is one of increasing importance and complexity, as the population of the country increases in number and density. Most large cities must take their supply from rivers, sometimes, as in the case of Philadelphia, constructing great filtering plants. New York and Boston have followed another policy of taking the whole supply of certain streams and carefully guarding the reservoirs and drainage basins against contamination. When the Croton supply became insufficient, New York went to the Catskill Mountains for water of the necessary purity, that could be kept free from pollution. Brooklyn is in part supplied from driven wells, which are carefully guarded against surface drainage. The cities on the Great Lakes take their water from those inland seas, carrying subaqueous tunnels several miles out from the shore to make sure of an uncontaminated supply. Havana is supplied from large springs, which is rather unusual, for the springs which can be grouped to supply one aqueduct are seldom of sufficient volume for a large town. Naturally, the sewage systems in use by various communities have a most important bearing upon the problem of water supply. Eventually the policy of discharging the sewers into rivers, convenient as it may be, must be abandoned for systems that are less wasteful and do not contaminate the waters. In the water supply of large cities the ground water plays but a subordinate part, except that it is all important as assuring the permanency of rivers.

However deep may be the downward penetration of water, there must be a limit below which it does not actively circulate. This is proved by the occurrence, only a few thousand feet below the surface, of very soluble substances, such as rock salt. The north German plain is underlaid by an immense body of salt, of unknown thickness, for none of the bore holes that have been put down have gone through the salt body.

The movement of ground water is excessively slow, though varying considerably according to the temperature and pressure of the water, the porosity of the rock, etc. In some instances the measured rate has not exceeded five or six feet per day, while in others it has been as much as ninety feet in a day. As the mechanical work done by flowing water depends entirely upon the velocity with which the water moves, it is clear that the ground water can accomplish no appreciable amount of mechanical wear in the rocks through or between which it passes. It does, however, do a considerable amount of chemical work by dissolving the soluble materials out of the rocks with which it comes in contact. That is the reason why the water in wells and springs is almost never pure, because of the gases and mineral substances which it holds in solution. The sparkling, refreshing quality of newly drawn water from well or spring is due to the dissolved gases, particularly the carbonic acid gas (CO_2) which all natural waters contain. When a glass of such water is allowed to stand until it reaches room temperature, the glass is lined with bubbles of the gas which the water gives off, and the flat taste of freshly boiled water is due to the lack of the gas, which is expelled by boiling. The quantity of gas which a given volume of water can absorb and dissolve is dependent upon the pressure to which the water is subjected, and also increases as the temperature is lowered. Many underground waters are under high pressures and are brought in contact with large volumes of the gas. When these highly charged waters reach the surface in springs, the diminished pressure allows much of the gas to escape, which it does, causing a more or less lively effervescence. These conditions are artificially imitated by a soda-water fountain, or a bottle of champagne.

Of the solid substances dissolved in ground water there is a very long list, though but few of these are found in any considerable quantity. The purest waters occur in granitic regions, and as they contain minute quantities of potash, they are remarkably soft. The commonest and most widely diffused of the dissolved substances is common salt ($NaCl$) which is rarely absent from any natural water. Almost equally common are lime compounds, especially the carbonate and sulphate, and those of magnesia. Between ordinary springs and those which are called "mineral," there is no very definite distinction, for the difference is one of degree, or quantity, and yet the distribution of mineral waters is such as to indicate that they owe their existence to certain definite conditions. Mineral springs are frequently hot, or thermal, and even when cold often occur in association with thermal springs. Confining attention to springs of the United States, we find that mineral springs, hot and cold, occur in two kinds of regions. The first kind is where volcanic activity has recently (i. e., in the geological sense) been displayed and where masses of highly heated rocks are still to be found not far below the surface. The countless thermal and mineral springs of the Yellowstone Park and the volcanic districts of California are referable to this class. Regions of the second class are the mountain ranges, where the rocks are profoundly disturbed by folding and traversed by great faults and fissures. Thus, mineral and thermal springs follow the Appalachian Mountains, from Ballston and Saratoga, in New York, southward. Virginia has many springs, especially the sulphur springs, which have been famous resorts for a long time past. Many of the Appalachian thermal and mineral springs are situated on the lines of fissure or faulting, through which the water rises from great depths.

The mountain ranges of the western side of the continent are generally accompanied by lines of thermal and mineral springs, but in the great interior basin, stretching from the Appalachian to the Rocky Mountains, there are springs only of the normal kind, with the exception of the hot springs of Arkansas. The mode of occurrence of thermal springs suggests the explanation of them. Over the great interior valley of North America, which forms the drainage basin of the Mississippi, the beds of rock are but little disturbed and, for long distances, are quite horizontal. In such rocks water cannot penetrate to great depths and find its way back to the surface. As if to emphasize the relation between disturbed rocks and thermal springs, the hot springs of Arkansas are placed on an island of profoundly disturbed rocks. Thermal springs, then, are of two classes, those of which the waters have been in contact with still uncooled volcanic masses, and those of which the waters have been warmed by a descent to levels where the earth's internal heat becomes effective. Many deep artesian wells yield lukewarm water, just because of the depth from which the water comes, and in certain mines and mountain tunnels described, hot water is a formidable obstacle to the workings. Very hot and boiling springs are found in volcanic regions, because in such regions, even though volcanic action may have died out long ago, highly heated rocks are near the surface and deep penetration of the water is not necessary for a hot spring.

Thermal springs are nearly always mineral springs, because hot waters dissolve many mineral substances which are unaffected by cold water, and they dissolve a larger quantity of the substances which are also soluble in cold water. Why cold mineral springs should have much the same distribution as thermal springs is not so obvious, but it may be inferred that the belts of disturbed and fissured rocks are favorable to the solution of minerals, even when the waters do not descend to great depths. Cold waters which contain sulphureted hydrogen in solution belong in a different category. Springs of such water are not confined to regions of disturbed rocks or of uncooled volcanic masses, but are determined chiefly by the occurrence of buried masses of decomposing vegetable matter.

Mineral springs, especially those which are warm, are in high favor for their curative value in several classes of diseases, and the places where they are found have long been favorite places of resort. Some "watering places" have been known and used for thousands of years, such as Aix-les-Bains in France and Bath in England, where the Romans constructed elaborate baths. Spa in Belgium, Vichy in France, Kissingen and Homburg in Germany, Carlsbad in Bohemia, are names that are familiar to everyone, and bottled waters from these famous springs are sold throughout the world. In our own country, before the coming of the European, many thermal and mineral springs were known to the Indians, who pointed them out to the newcomers. Saratoga and the Buffalo Hot Springs, in the Black Hills, are but two of the many places resorted to by the Indians for the cure of their ills.

The behavior of ground water in limestone regions is quite different from that in regions of other kinds of rock, because limestone is slowly dissolved by ground water and, still more slowly, by surface waters. Limestone thus occupies an exceptional and anomalous position among the rocks; while very often hard and resistant, standing out in bluffs and ledges as the conspicuous features of a landscape, because the other and softer rocks have been removed more rapidly, it is, when pure, completely soluble in water. Usually, limestones contain a greater or less quantity of impurities, which, most commonly, are of clay or sand; the impurities, which may be as much as 40 per cent of the rock, are left behind as a residual soil. The quantity of limestone which any given volume of water will dissolve depends upon the amount of carbonic acid gas (CO_2) which the water contains and that, in turn, is determined by the pressure to which the water is subjected. It has been noted previously that many mineral waters are so charged with this gas, that when they reach the surface in a spring and the pressure is released, the gas bubbles are given off so rapidly as to make the water effervescent. Underground, such carbonated waters dissolve large quantities of limestone, but, when they come to the surface in springs and a large part of their carbonic acid gas has escaped, the water can no longer retain in solution most of the dissolved limestone and so deposits it on the surface. At Tivoli, near Rome, is an immense body of this spring-deposited rock, called *travertine,* which was quarried on an enormous scale for the ancient city and is still extensively used. The stone which lines the great concourse of the Pennsylvania Railroad Station in New York, was brought from Tivoli.

At the Mammoth Hot Springs, in the Yellowstone Park, a beautiful series of travertine terraces has been built up by the springs which issue at the top of the mountain, and their waters trickle down from pool to pool, depositing travertine in their flow. In this instance, however, the action is not entirely chemical, but is assisted by microscopic plants. The geyser district of New Zealand formerly contained two such formations, known as the Pink and the White Terrace, which were famous for their remarkable beauty. Unfortunately they were destroyed by the earthquake of 1886. While such terraces as those of New Zealand and the Yellowstone Park are exceptional, masses of travertine made by springs are not uncommon.

The waters at Tivoli are so highly charged with dissolved limestone, that they form an incrustation upon everything that they touch. Even when they are not so surcharged with lime, the waters of limestone districts are always "hard"; i. e., they decompose soap, converting it from a soluble potash or soda soap into an insoluble lime soap, and making the unpleasant-looking curdling, which is characteristic of hard water and makes it unsuitable for laundry purposes. Soft water is free from dissolved lime compounds. Hard water is also unsuitable for use in steam boilers, because boiling drives off all the contained gases, and all the dissolved limestone is deposited as "scale." Sometimes as much as three or four inches of scale form on the inside of the boiler and then the boiler is in a dangerous state, because the steel plates of the fire box, being no longer in contact with the water, may be made red-hot and thus softened and greatly weakened, so that they yield to the steam pressure and burst asunder. A great many boiler explosions are due to scale. There are ways of treating hard water chemically, so as to rid it of the lime; but this is costly and troublesome. Though hard water is especially characteristic of regions in which limestone rocks occur at or near the surface, it is not confined to such regions, for lime compounds are widely diffused among the rocks and in sufficient quantity to appear in the water which traverses those rocks.

Underground, the water dissolves out channels in limestones in which considerable streams run, and continued solution enlarges the channels into great caverns. These caves and caverns often extend for many miles and are invariably found in limestone. Shallow, surface caves may be carved in any sort of rock by whirling sands driven by the wind, but true underground caverns are always in limestone and occur in all limestone regions. Many of these, like the Mammoth Cave in Kentucky, and the Caverns of Luray in Virginia, are famous for their vast size, or for the extraordinary beauty of their chambers, adorned with stalactites and stalagmites. These are dissolved and redeposited limestone and assume an astonishing variety of forms. A drop of water, charged with lime, hanging from the roof of a cavern, will deposit a ring of calcareous matter and, when it falls, begin a similar deposit on the floor. The innumerable repetitions of this process will form an iciclelike stalactite depending from the roof and a similar stalagmite rising from the floor. If the water continues to follow the same channels, stalactite and stalagmite will eventually meet and unite to form a pillar, which is thickened as the water glides down its exterior. It will readily be seen that the manner in which water drops or trickles, now fast, now slowly, in varying volume and lime content, from the roof of a cavern to its floor, provides means for producing great variety of forms in the deposits.

In the long, slow ascent of man from savagery and barbarism the cave played an important part, as affording shelter and a means of defense against the fierce and bloodthirsty beasts which early man had to confront with his pitiful weapons of stone and horn. The Cave Man in Europe, perhaps also in America, was surrounded by hordes of huge and terrible brutes, most of which are now extinct, much to the improvement of the earth as a dwelling place for man. The very wonderful paintings still to be seen in the caverns of the Pyrenees and the south of France have preserved a record of these brutes, which were already known to us from their bones. The extraordinary skill displayed in these paintings is shown by the fact that the modern naturalist can identify the species of animals which the drawings portray. The cave entrance is usually defensible, or could easily be made so, and it may very well be true that it was the cave which made it possible for early man to get and keep his foothold in Europe, until the great beasts of prey, like the Cave Lion and the Cave Bear, had vanished from the scene. So far as America is concerned, it is still a question when man arrived in the Western Hemisphere from the Old World, and whether the great extinction which, over more than half of the earth's land surface, swept away the largest, fiercest, and most formidable of the animals, occurred before or after man's arrival in America. This is a topic which is much debated, but no convincing conclusion has yet been reached.

Limestone regions are the only ones in which large, flowing, underground streams are to be found, for limestones are the only rocks in which sufficiently large channels for real streams can be formed. Streams flowing through areas of which the rocks are of the ordinary insoluble kinds very frequently disappear underground when they reach a district of limestones. In maps of such countries, of which Kentucky and Tennessee may be taken as examples, one may frequently note that numerous small streams reach a certain line and then disappear; such a line indicates the coming of a limestone to the surface. After a longer or shorter course underground, the streams may reappear on the surface and, during times of flood, when the subterranean channels are filled to their capacity with water, the surplus finds an outlet along surface channels. In what was formerly Austria, the Reka is a stream flowing in an open valley, which is cut through sandstone, until it reaches a limestone belt, where it enters a cave near St. Canzian and reappears in a great spring on the shore of the Gulf of Trieste, and also in other springs along the shores of the gulf for a distance of thirteen miles. By means of chemical tests, it has been made plain that below the surface the Reka divides into a large number of separate, subterranean channels, and thus comes into connection with other streams from which, on the surface, it is widely separated.

Around the northern end of the Adriatic Sea and following down its eastern shore is a remarkable region known as the Karst; it is composed of limestone rocks, traversed by great numbers of parallel faults, which have greatly shattered the surface rocks. Water descends readily through the broken rocks and has also made ways for itself by vertical funnels and pipes, leading down to a network of caverns and subterranean channels below. In the absence of all surface waters, a barren, desolate region, without vegetation and largely without soil, is the result. However heavy the rainfall, the water is rapidly drained away below the surface and a stony desert is formed. Similar landscapes in other parts of the world are called "karsts" from this district.

Peculiar conditions of the ground water are found in the desert basins of central Asia, where are formed the oases which have played such an extremely important part in the history of Indo-

European civilization. The precipitation of central Asia is almost entirely in the form of snow upon the tops of the very high ranges of mountains and the melting snows give rise to streams which, for a distance determined by their volume, flow down into the desert basin and either die away in the sands or gravels, or end in salt lakes. On the mountain slopes the streams are very swift and sweep along all cobblestones and coarse gravel, which are deposited in a broad band of gravel at the foot of the mountains. Much water is absorbed in these dry gravels and comes to or near the surface at the edge of the gravel belt on the basin floor, giving moisture to the ground and permitting the growth of a belt of vegetation, trees, and shrubs.

In the foregoing account of the ground water and of springs, it has been taken for granted that all of the water is derived from atmospheric precipitation, rain or snow. There are, however, among geographers and geologists, several very high authorities who maintain that certain springs are supplied with "juvenile" water, which has never before been on the surface of the earth. This is the supplementary supply already referred to at the beginning of this chapter. The molten rock masses in the earth's interior contain great quantities of steam, which is given off as the masses which have invaded the upper parts of the earth's crust gradually solidify by the crystallization of their constituent minerals. The water thus extruded from the igneous rocks, as they cool, is conceived of as supplying the juvenile springs, which are characterized as being independent of the weather and in the amount of discharge, and the quantity and proportion of the dissolved mineral substances, remaining constant throughout the year. Ordinary springs, it is maintained, fluctuate in both respects in accordance with the periods of drought or of wet weather. This is an interesting speculation which has not yet been proved, nor can it be definitely shown that such springs do not exist. The most that can be shown is that a particular spring is or is not formed in this way. The Sprudel, at Carlsbad in Bohemia, has been selected as a type of the spring supplied with juvenile waters.

The constancy of volume in a spring and its independence of the weather are conditioned by the size of the reservoir which supplies it; deep fissure springs of large volume are very constant, as are most deep artesian wells. It is a suggestive fact that the springs which have been described as juvenile are, almost without exception, situated in regions of normal precipitation; the deserts should have their due proportion of them. However, should the widest claims made for the juvenile springs be admitted, they would but slightly modify the principles of the circulation of water, which have been assumed in this chapter.

CHAPTER VI

THE DEVELOPMENT OF RIVERS

THE classification of rivers is made by geographers from several different points of view. One distinction that is universally drawn, both in popular speech and in scientific terminology, is that between trunk stream and branch, but it is not always easy to decide to which category a given stream belongs. Should not the Missouri, for instance, be regarded as the upper Mississippi, rather than the stream which is so named? In estimating the length of river systems, the Mississippi-Missouri length is always the one taken for the great North American system. A second distinction is that between marine and continental; marine rivers are those which enter the sea, and the continental rivers those which do not. Of course, the great majority of rivers belong to the marine class, but some large streams are continental, the greatest of which is the Volga, that enters the Caspian Sea, but has no connection with the ocean. This division is too unequal to be of much importance. A third distinction is with reference to the "grain of the country," into longitudinal and transverse rivers, as we have already found there are both longitudinal and transverse valleys, which may or may not be occupied by rivers. Longitudinal rivers are those which flow parallel to the great lines of folding and faulting, such as the Danube, the Po, the Shenandoah, the Holston, and other streams of the southern Appalachians. Longitudinal rivers may flow for long distances in the same strata of rock, because they follow the lines of outcrop along which those strata come to the surface of the ground, and their course is more or less closely parallel to the main lines of watershed. Transverse rivers, such as the Delaware, the Susquehanna, and the Potomac, flow directly away from the main watersheds, more or less nearly at right angles to them, and cut across the lines along which the strata come to the surface, so that the kind of rock in the channel is constantly changing. The distinction of longitudinal and transverse streams does not apply in a region of horizontal strata, because such a country has no grain, but the relation to the watershed is retained.

A fourth scheme of classification is in accordance with what may be called the structure of the river. A normal stream has a course divisible into three parts, the upper or torrential part, the lower, more sluggish, and depositing part, and a middle part between them. This fourth plan divides rivers into *homogeneous*, which have a course of only one kind, like the streams of a coastal plain, the headwaters of which do not extend into the uplands, or, at the other extreme, the torrents which rise in coast ranges of mountains and empty directly into the sea, without a lowland course. *Heterogeneous* streams are those which have two or more different kinds of courses, and most rivers, including almost all the longer ones, are of this class. The heterogeneous streams, again, are of two kinds, those which pass through the different varieties of course but once and those in which the courses are repeated, it may be several times. The Delaware, Susquehanna, Rhine, and Danube, are streams of this sort, but especially characteristic are the great African rivers, which, after a tranquil, open course across the great plateau of interior Africa, have their lower courses broken by waterfalls. The Nile, the Congo, the Zambezi, are instances of this type of stream. Supan says: "Alternations of course always indicate that the river is composed of several originally independent streams and has passed through a complex development."

The preceding classifications deal with rivers as we find them at present. A better classification is the genetic scheme of arrangement, proposed by Professor Davis and widely adopted by geographers and geologists. Like all genetic schemes, this cannot always be applied, because its application requires a knowledge of the history of the streams, and this knowledge cannot in all cases be obtained. The development of river systems follows the succession of cycles even more plainly than does the development of land surfaces. The youth, maturity, and old age of drainage systems may in all cases be plainly distinguished by characteristic marks.

Let us imagine, to begin with, an entirely new land surface, of large area, upheaved from beneath the sea. We know no instance of the sort; in historic times no large area of the sea bottom has been raised into land, so far as is known. It must be remembered, however, that much the greater part of the earth's surface has been known to civilized man but a relatively short time, and many things may have taken place within historic times, of which we have no record and which we cannot date. We see the result and can affirm that this result was produced in geologically recent times, but whether it took place within the very brief space of time which we call the historic period, we cannot, in the absence of witnesses, definitely decide.

Our imaginary land surface may be made to serve a very useful purpose in making clear the genesis of river systems. Such a new area as we are postulating will have no streams and will be drained entirely by surface wash according to the slope of the new land; or, according to the slopes, if there are more than one, as would probably be the case. The slope, or slopes, of the new land would not be perfectly plane, nor would the rocks, of which the new land is built up, be perfectly homogeneous. There must have been slight depressions, in which the rain water would gather into rills and these rills would cut little trenches and gullies, as they may be seen to do on any land surface which is not protected by a dense covering of vegetation.

A new land, just raised above the sea, would be rapidly or slowly invaded by plants, in accordance with the nearness or distance of the older lands from which the plants came; but, however quickly the invasion was accomplished, there would be a considerable period before the ground was so covered as to be effectually protected. Thus, rill-made trenches would be numerously formed and certain ones of these would be more favorably situated than others and would carry more water after rains. The more favorably situated trenches would be more rapidly broadened and deepened by the washing action of storm water into ravines. In this early stage there would be many ravines cutting into all the slopes, and those of each slope parallel with one another carrying no permanent streams, but merely acting as discharge drains for the rain water. Those ravines which were more rapidly deepened would be the first to reach the level of the "water table," or ground water, and when that was reached, a line of springs would be formed, and these would convert the rain trench into a real stream. As the level of the ground water rises and sinks with the seasons of heavy or light rainfall, the new streams would at first be periodical until their channels were cut to a level at which the springs do not run dry even in the driest seasons, and then the streams would become permanent. We are assuming a climate of good rainfall and need not consider the modifications of scheme introduced by differences of climate.

If the new land were not a single, simple slope, but a folded area, the valleys formed by the downward bending of the rocks would be the principal drainage lines, and these valleys are longitudinal. These valleys of folding are connected at points where the intervening ridges die down into the valley level, and, though new ridges rise to take their place, the ridges are not continuous, but offset, with gaps between them. A stream may thus pass from one valley to another, even before the ridges are cut through by the encroaching stream. Both of these methods of communication from valley to valley may be seen in the Jura Mountains. Thus, in a newly formed land, the streams are determined entirely by the slopes of the new surface, are consequent upon those slopes, and are called *consequent* streams because of that fact.

Southern Florida very nearly exemplifies the hypothetical new land surface, newly upheaved above the sea, though that upheaval did not take place in historic times. Its streams bear all the characteristics of extreme youth. A very young stream drains its territory very imperfectly, and much of that territory has not been drained. Whatever depressions of the surface may exist fill up with water and form lakes, the remarkable abundance of which is one of the most striking features of the Florida landscape. The tributaries of a young river are few, fewer than they afterward become, and the watersheds between them are low and obscurely marked. The Red River of the North is a very youthful stream that flows across a plain which is almost perfectly flat, being the floor of an abandoned lake. On this plain the divides between the streams are so broad and flat that after heavy rains the water lies upon them in great shallow pools, having no reason to flow in one direction rather than another, for there is almost no slope. In northern Minnesota is the divide between three drainage systems, the Mississippi, the St. Lawrence, and the streams flowing into Hudson Bay. So flat is the country that the watersheds are hardly noticeable; the streams are sluggish for want of slope. Though Minnesota and the surrounding areas are very old lands, their present topography is new, owing to the relatively recent events of the Glacial Epoch. The Pampas of the Argentine Republic, east of Buenos Aires, are likewise extremely flat, and the disposal of the heavy rainfall is a practical problem of great importance. The Argentine Government has expended large sums in works for the removal of the rain water, which lies on the ground without flowing in any direction.

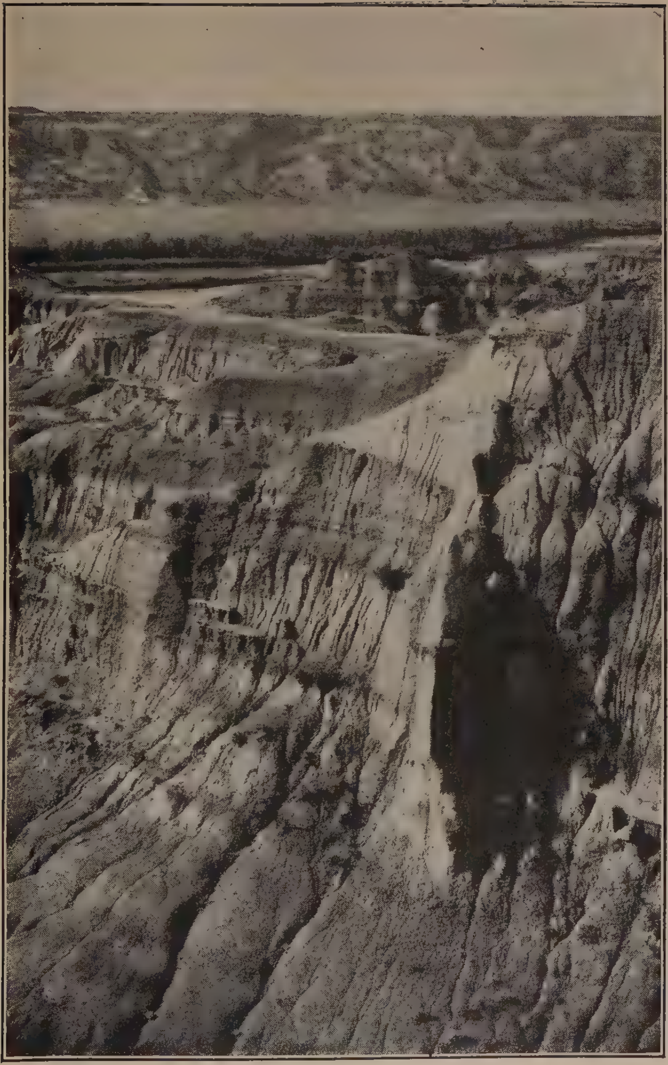
As the river system matures, the channels are cut down and the larger streams rapidly reach base level, below which vertical cutting is impracticable. The depth of the river gorges and cañons is dependent upon the altitude of the country above sea level, from which it follows that very deep cañons are possible only in regions of great altitude, either of plateau or mountain range. It is not necessary that this altitude should have been attained before the river began its work. For example, there is much reason to believe that the high plateaus, through which the Grand Cañon of the Colorado has been excavated, have long been rising. Like a log in a sawmill, which is fed against a saw in a fixed position, the rising land is fed against the river and, by keeping the current at a maximum of activity, facilitates very rapid excavation of the gorge.

Waterfalls in the main or trunk stream are characteristic of a youthful stage of development, and are caused by the crossing of hard ledges in the channel. These are rapidly cut through and the falls disappear, but they may persist almost indefinitely near the headwaters of the main stream and its branches. A reelevation of the country, which rejuvenates the streams, will cause the waterfalls to reappear through establishment of the same conditions, which is frequently the explanation of the occurrence of rapids and cascades in old rivers, such as the Delaware and the Potomac.

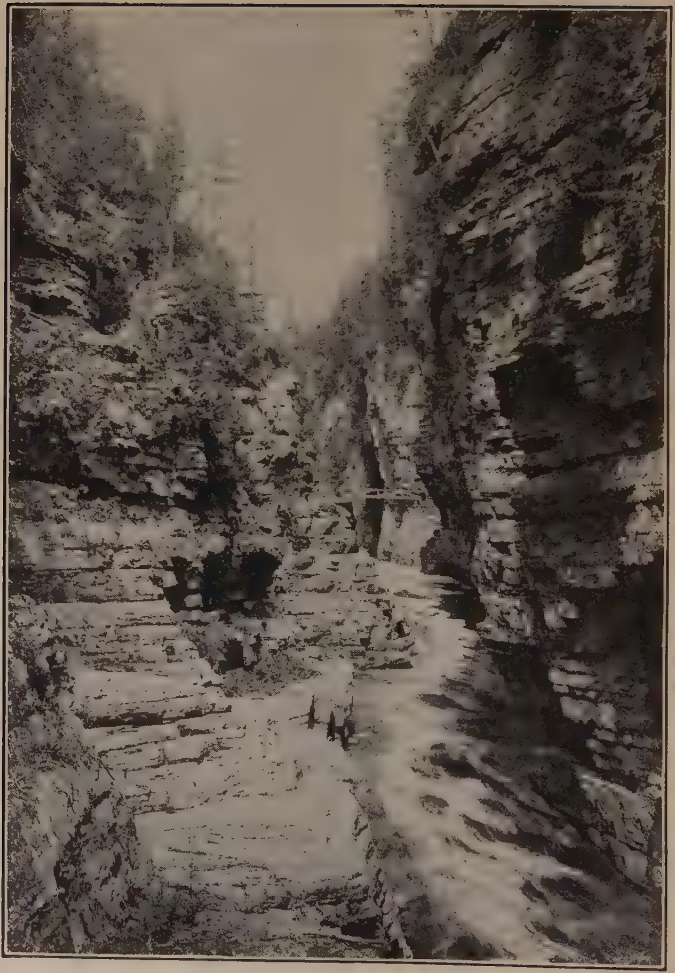
By the aid of atmospheric cooperation, the main valleys are widened out, and on their sloping sides new tributary streams are formed which are called *subsequent* and, when the development of the river system has attained its mature stage, it has so multiplied its tributaries and their ramifying branches that all parts of the basin are reached and drained. Certain of these newly established tributaries will be found flowing in opposite directions from those followed by the consequent streams; such streams are said to be *obsequent.* A large scale map that accurately gives the mature drainage in a climate of abundant rain shows the really extraordinary multiplication of streams and the way in which they ramify to every point of the basin. Southern New Jersey is a good example of this, but in this part of the coastal plain the rocks are unconsolidated and therefore there is not the adjustment of the streams to the rock structure, which in regions of ordinarily hard rock and mature drainage is so remarkable. Few lakes, or none at all, persist in regions that have reached maturity of drainage.

The adjustment of streams to rock structure, which may be observed in regions of mature drainage, in which the rocks are consolidated and not loose materials like those which make up the coastal plain, consists in the taking advantage of every line of weakness in the rocks to render easier the excavation of channels and their valleys. The weakness may be in lines of soft rocks, of faulting, folding, or jointing, or all of these. When the rivers are mature, the valley floors are broadened and the streams deposit part of their load of sediment upon them, especially in seasons of flood, when the flood plain is inundated with slow-moving water which throws down material, when the swift current in the river channel prevents any such deposition there.

When the rivers have reached base level, which they do quite rapidly and, frequently, long before the youthful stage of river development has been



HORIZONTAL SANDSTONE IN THE RED DEER RIVER DISTRICT OF CANADA



AUSABLE CHASM, NEW YORK, A YOUTHFUL RIVER-MADE GORGE passed, they can no longer continue to deepen their valleys, but they can widen them by lateral cutting and undermining. They also receive and carry away the material which is washed in by the rains, and thus the divides between streams are lowered and eventually worn away, so that the reason why a stream runs in one direction rather than another may be no longer obvious. In a mature system of drainage, the network of streams is complete, and the valley surfaces have been so enlarged that the rate at which the land is being worn down is accelerated and a greater load of sediment is brought into the trunk stream. In maturity, the load of a stream reaches its maximum, and is sometimes so great that the lower portion is unable to carry it all and spreads the excess out over the flood plain. The channel of an overloaded stream is raised and banked in by its own deposits, and this may be carried to such an extent as to deflect the tributaries, which are forced to run parallel to the main stream and may be cut off from it altogether, so as to enter the sea independently. In Nebraska, the Platte River (which Bill Nye described as being "a mile wide and an inch deep," without too gross exaggeration) is heavily overloaded, and has built up a ridge by depositing that overload and flows along the ridge. When the Loup Fork descends into the valley of the Platte, it is unable to reach the main stream and flows parallel with it for many miles before it finds an opportunity to join the trunk river.

When a river is allowed to overflow its flood plain annually without interference, lines of maximum deposition form along the lines of contact between the swiftly flowing water of the channel and the relatively still water over the flood plain. Because of this, the ground slopes *away* from the river on each side of the lower Mississippi. By artificial interference, these processes may be much modified, sometimes disastrously. If levees are built which prevent the annual inundation of the flood plain, the confinement of the flood water within the narrow channel greatly increases the velocity of the current, which may cause the river to scour and deepen its channel. If, however, the flooded stream is heavily overloaded with sediment and unable to carry it all, even with the increased velocity due to confinement, it will build up its bed by deposition. As the bed is raised, the levees must be raised correspondingly, until a dangerous condition is reached.

Old age of a river system is reached when all the streams are at base level and the area drained by the system has been reduced to a low-lying plain. The sluggish streams meander in sinuous, winding channels through masses of their own deposits. Meandering, however, is not confined to sluggish streams; any river, flowing in soft, easily removed material, and in a valley of little slope, will meander, as does the lower Mississippi, despite its strong current. Many of these meanders are true "oxbows," a narrow neck of land, a mile or two in width, may separate two points of the river which, following the channel, are ten, fifteen or twenty miles apart. Occasionally, the river will cut through the neck, abandoning its old channel and converting it into an "oxbow lake," while starting a new meander elsewhere. This constant shifting of its channel in the soft alluvium by the great river is the despair of engineers who are striving to control it so far, at least, not very successfully.

When its drainage basin has thus been smoothed down, the river's work is completed and, so long as the land remains at the same small altitude above the sea, further change will be extremely slow. There is much geological evidence to show that land areas may, for long ages, lie just above sea level and undergo hardly any appreciable change, until a new cycle is initiated by an elevation of the region, when a period of relatively rapid change again sets in.

Cycles are seldom complete. Almost always they are interrupted in one fashion or another before the ideal state of old age is reached. An elevation of the region may simply rejuvenate the streams, giving them new power by increasing their height above sea level and, therefore, increasing the slope of their beds and consequently their velocity. Upon velocity depends the cutting and transporting power of a river. The upheaval may be accompanied by warping or folding of the rocks and, if so, the drainage of the region elevated may be completely revolutionized. Whether this revolutionizing of the drainage system is or is not to take place, will very largely depend upon the rate at which warping or folding of the rocks is effected. If it is done rapidly, the drainage will surely be changed, but if it is accomplished very slowly, the streams may be able to cut down into the rocks as fast as these are raised and so maintain their previous courses.

The reelevation of a region begins a new cycle, whether the preceding one was complete or not. Depression, on the other hand, may practically end an old cycle without beginning a new one, although, theoretically, a cycle continues until its successor is inaugurated. Depression will diminish the cutting power of the streams, or, if sufficient in amount, will put a stop to it altogether. The lower reaches of the streams are invaded by the sea and converted into tidal estuaries, in which case the valleys are said to be drowned. Base level is thus reached much sooner than it would have been in a stationary region where crustal movements were not occurring. The cycle of certain rivers may be brought to a premature end by a climatic change toward desiccation, in consequence of which many stream channels are abandoned. The outlet to the sea may be cut off, establishing a new base level, which may be either above sea level, as in the case of the streams of the Great Basin, or below it, as in the instance of the Volga or the Jordan. The lava outpouring which took place on such a vast scale in the Northwest obliterated the drainage system by filling up the valleys and necessitated the establishment of a new one, as did also, so far as the minor drainage was concerned, the drift sheet left behind by the retreating ice of the Glacial Epoch. The great rivers resumed their pre-Glacial courses, when the ice disappeared, but the smaller valleys were filled.

A fourth class of rivers comprises those which are called *antecedent* and which maintain, after a crustal movement of uplift, warping, or folding, the courses which they took before the disturbance. They are antecedent to the crustal movement, and thus a stream that was consequent in one cycle, consequent upon the original slope of the ground, may become antecedent in the next. It may, however, be diverted to an entirely new course and again be consequent on the new slopes. The simplest case of antecedent drainage occurs where the region in question is elevated without deformation or dislocation and without changing the direction of the slopes. In such a case, the streams all keep their old channels and are simply revivified by the increased slope of their beds. Streams which are flowing down extremely gentle slopes are apt to meander, especially if the river bed be in soft and incoherent materials. Meandering is a very general characteristic of old age, but may occur in a river in which, like the lower Mississippi, the current remains swift because of the great volume of water. If a meandering stream be reelevated and the crustal movement is sufficiently slow, so that the stream's velocity is not suddenly and greatly increased, it retains the meandering course while cutting into the hard underlying rock. In such a case the meanders are said to be "intrenched," and thus a meandering gorge, with high, steep walls of rock, is formed. Intrenched meanders are a strong indication of a reelevated region and an antecedent stream. The valley of the Moselle between Trier and Coblenz is a deep gorge of continually repeated meanders; had the movement of reelevation been so rapid as to give the river great velocity, the meanders would have been cut through and the valley straightened.

There are, in various parts of the world, very remarkable instances of rivers, of which the paradoxical courses are usually interpreted as antecedent, but which may, perhaps, be susceptible of other explanations. One such case is that of the Columbia, the great river of the Northwest. The volcanic plateau of that region deflects the river westward to the foot of the Cascade Mountains, where it turns southward and follows the mountains for some distance, until it again turns westward and cuts through the mountains in a great cañon. Probably the river is older than the mountains and cut through them as they rose across its course. The Snake River, a tributary of the Columbia, has cut a great gorge, 6,000 feet deep, through exceptionally hard rock, lava, and granite. A slowly rising upwarp of the rocks has been trenched by the river, which was able to keep pace with the movement and thus maintain its channel.

A most remarkable, and as yet not definitely explained, case is that of the Green and Yampa Rivers in the Uinta Mountains. The Green River, coming down from the north, meets the barrier of the lofty mountain range, whose snow-covered ridges and peaks would seem to offer an insurmountable obstacle; it would be easy for the river to avoid this obstacle by flowing eastward along the foot of the range into northwestern Colorado, where the Uintas die down into the White River plateau, and thus turn the flank of the mountains around their eastern end. Far from doing this, the river flows right at the mountains and cuts the great cañon known as Flaming Gorge, until it reaches the axis of the range, when it turns eastward, then southward, and then westward, in a series of profound cañons, which cut through the very heart of the mountains.

The Yampa behaves in a more peculiar fashion. Coming from the east, one would naturally expect it to be deflected into the low country on one side or other of the Uinta Mountains. In fact, it flows directly westward along the axis of the range, cutting a deep cañon, and joining the Green River in the heart of the mountains.

Such behavior is by no means exceptional, but occurs the world over, and people in the eastern United States need not travel far to find examples, for the northern Appalachian rivers are excellent illustrations. The great streams of the eastern United States flow across the mountains, not with them; that is to say, they occupy the transverse and not the longitudinal valleys. The Delaware crosses the range in the well-known Delaware Water Gap; less famous are the gaps of the Susquehanna, the Lehigh, and the Potomac, and of many smaller streams that flow in a similar manner. Most of the Atlantic coast rivers cut through one or more of the Appalachian ridges, instead of flowing down the great Appalachian Valley to the Gulf of Mexico, as one would expect from the examination of a map or relief model. This great valley has different names for parts of its length, as the Cumberland Valley below Harrisburg, the Shenandoah Valley in Virginia, etc., and runs through Pennsylvania, Maryland, Virginia, and North Carolina, but is not occupied by a trunk stream. Many streams follow it for a distance, and then cut through a ridge.

Rivers that rise in the interior of the Alps and the Himalayas, or that cross the southern Andes, show the same apparent disregard of the easy and obvious course and select, one is tempted to think, the difficult one. In attempting to explain the extraordinary courses taken by many streams, two facts must always be borne in mind. Of these, the first is that, in the great majority of instances, rivers have themselves made the channels in which they flow. Sometimes, as in the middle valley of the Rhine and the whole valley of the Jordan, the stream follows a rift valley due to faulting, or a valley of folding, as in the Jura, but these are exceptional. The second fact is that rivers never flowed uphill, as it would often seem necessary to believe that they did, on the assumption that they cut their own channels. When they began their flow and established their valleys, the topography was different from what it is now and the course which they then took was the one which they were compelled to take by the then existing slopes, and it is the modern topography which seems to require the uphill flow. The problem is to determine what the ancient topography was like, and often the chief difficulty in doing this lies in selecting the right explanation out of several possible alternatives. The Green and Yampa are generally regarded as antecedent, older than the mountain wall which they have so profoundly gashed; there are, however, other and equally plausible explanations and, until the history of the region has been thoroughly studied, the choice between the alternatives cannot be positively made.

The equally paradoxical, though far less striking, cases of the Appalachian rivers may be explained with a considerable degree of confidence, because the history of the mountains has been made out in a good deal of detail. This history shows that the mountain ranges are of great geological antiquity and that the denuding agents had for ages attacked them and worn them down to a low-lying, almost featureless surface, but little above sea level. A few higher points remained, like the mountains of western North Carolina, where, in Mount Mitchell, the greatest altitude east of the Black Hills is found to-day. Aside from these low residual mountains, the rest of the Appalachian system was nearly a plain, without longitudinal ridges and valleys. When such transverse rivers as the Delaware, the Susquehanna, the Potomac, began their course, they were consequent upon a simple slope eastward to the sea and flowed along this slope without meeting any particular obstacles. The eastward slope had been caused by a relatively recent upwarp, which had raised the nearly flat surface into a low and very gently sloping domelike surface, with the summit in Virginia and inclining in all directions from that point. The amount of uplift was sufficient to insure the cutting of gorges that were of considerable depth, and thus the rivers intrenched themselves in an easterly course, cutting across hard beds and soft with no great difference of rate. Out of this upheaved dome were gradually cut by atmospheric weathering the longitudinal valleys, which, though they coincide with the axes of folds, are still not valleys of folding, but of excavation, as is shown by the fact that all of these longitudinal valleys are cut out along the softer rocks. The ridges which form the present mountains are everywhere due to the outcropping of inclined beds of hard and resistant rocks and thus the ridges are younger than the streams, which had cut through them before they were etched into relief by the excavation of the longitudinal valleys. Except in the very hard rocks, the transverse stream valleys were greatly widened into the form typical of mature stream valleys, as is very well exemplified by the Delaware both above and below the Water Gap. The broad portions of the valley are cut out of the softer rocks; the deep gorge of the Gap is where the river has trenched the very hard rocks of the Kittatinny Ridge, before that ridge had been made visible above the general surface by the removal of the rocks on each side of it. This is the story of the series of gaps which notch the Appalachian ridges, though many of the gaps have been deserted by the streams that made them and are now "wind gaps."

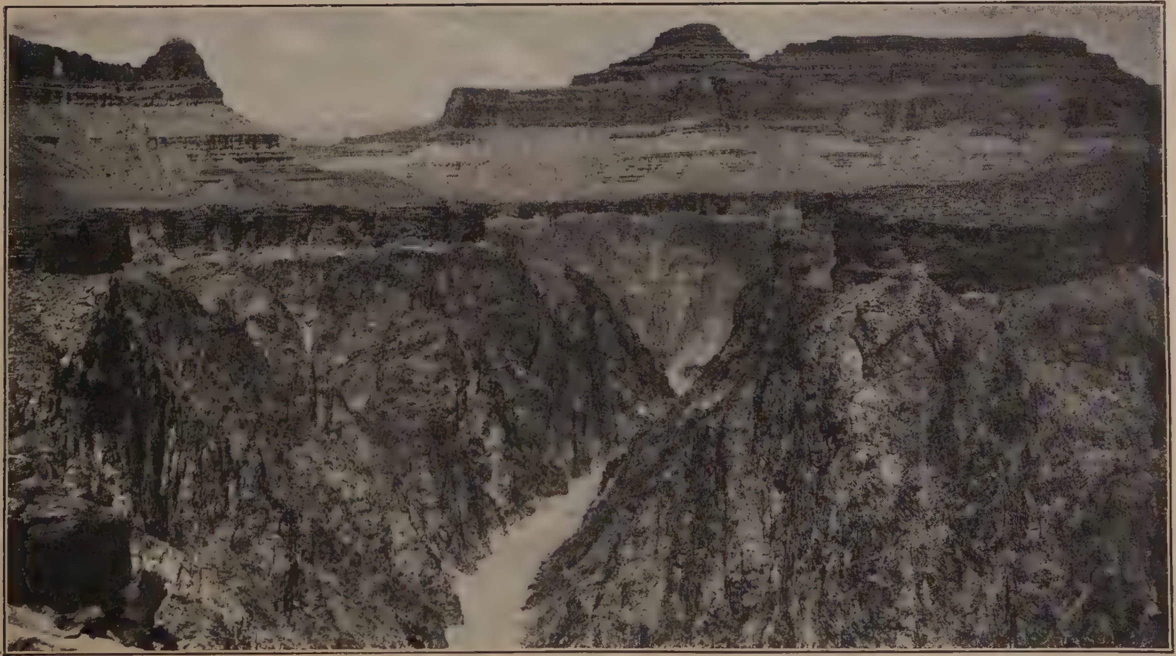
The same result may be attained by antecedent rivers which had intrenched themselves so deeply before the movement of upheaval began that the movement was powerless to dislodge them. On the other hand, the elevation may have been so slow that the streams were able to cut through the obstructions as fast as they rose.

Still a fifth kind of rivers, in this scheme of classification, is the *superimposed.* An old topography may be buried out of sight by one or more of the various methods of deposition and accumulation. The great lava plateau of the Northwest is an instance of this sort, where 250,000 square miles of old topography has been buried out of sight, its valleys filled up and obliterated and its hills submerged under the floods of molten lava which solidified into a hard black rock, and left a flat surface which gave no hint of the old land surface beneath. Another method is exemplified in the northeastern United States and adjoining parts of Canada, where the surface is now formed to a very large extent by the masses of drift which the retreating ice sheets of the Glacial Epoch left behind them. This drift completely changed the minor topography of the country and produced a general southward slope. Hundreds of valleys buried under the drift have been brought to light by the borings made for oil and gas in western Pennsylvania, Ohio, Ontario, and Indiana. Using the records of these wells, the buried valleys have been mapped and their drainage system reconstructed. All over this region, the ancient, pre-Glacial drainage was northward to the St. Lawrence, for the Great Lakes were not then in existence. When the ice disappeared, only the large rivers were able to reoccupy their old channels and, no doubt, those which, like the Delaware and the Susquehanna, had their lower courses extending beyond the limits of the ice, continued to flow in those courses during the Glacial Epoch.

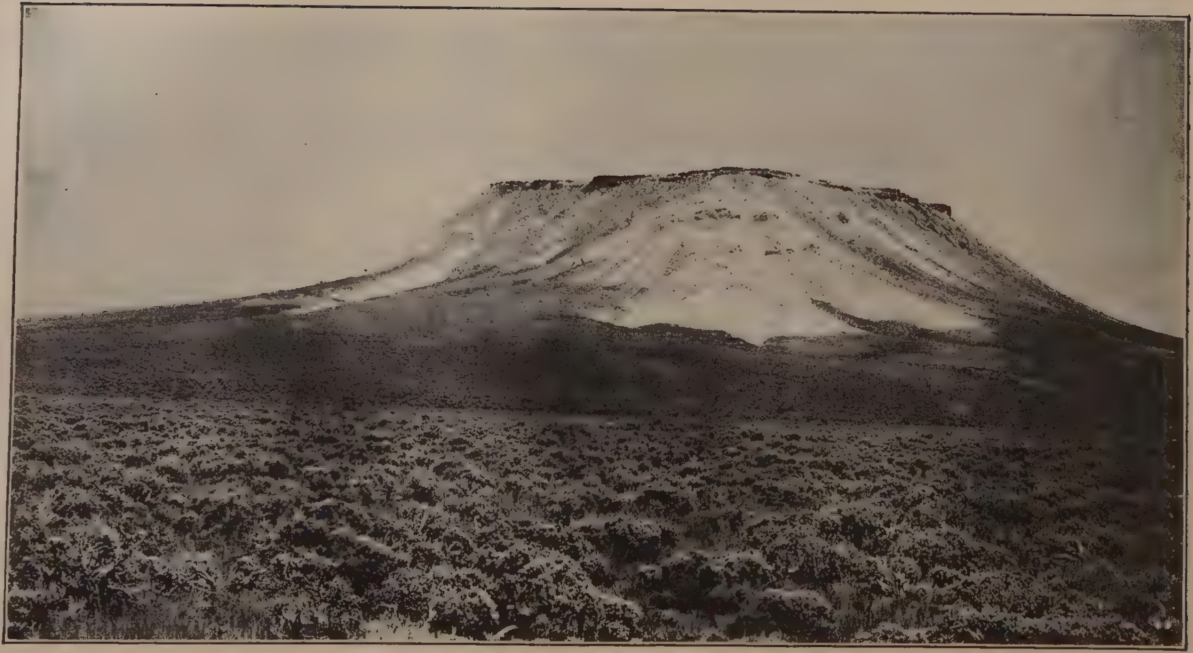
Upon the new surface, laid bare by the retreating ice, a new system of drainage was established, to take the place of the old minor streams, which had been obliterated and their valleys filled up. The general slope of the new drift surface was southward and the new streams were consequent upon this southward slope, but should be classed with superimposed, rather than with consequent streams. The new streams rapidly cut through the loose and incoherent masses of drift and began to excavate channels in the underlying hard rocks, but they were entirely out of adjustment with the structure of those underlying rocks; indeed, they had no reference to it at all. The older rocks, beneath the mantle of drift, form an irregular surface and the newer streams, except when they happened to coincide, more or less partially, with buried, pre-Glacial valleys, first encountered the higher and more prominent of the ridges beneath the drift; these ledges caused waterfalls and rapids, which there has not yet been time to wear away. Sometimes, the drift has been removed from considerable areas, and then the lack of correspondence between the streams and the rock structure seems inexplicable because the drainage was established on a surface which no longer exists.

The upper Mississippi is a superimposed stream which has cut through the drift sheet in many places and is cutting into the hard and very ancient underlying rocks. An exceptionally hard ledge forms the Falls of St. Anthony at Minneapolis. The many small gorges, cut in soft rock, which are found in central New York, retain their vertical sides despite the easily destructible character of the rock in which they are cut and the moist climate of the region where they occur.

The streams which have cut through the lava cap of the great basaltic plateau of the northwestern States, are also superimposed and bear no relation to the topography or the structure and arrangement of the rocks which lie buried under the vast outpouring of lava. Many streams have cut down through the lava into the underlying rocks, and there is complete lack of adjustment between the streams and the buried rocks. Of a similar kind are two streams in western Colorado, the Gunnison and its tributary, the Uncompahgre, which present an extremely curious case of superimposed drainage, which would be quite inexplicable if the history of the region were unknown. These two streams began their course upon a plateau, the surface of which sloped to the west, and which was chiefly built up of a volcanic ash that was quite soft and easily removed. The volcanic accumulations, which were very different from the hard black lava of the northwestern plateau, to which reference has just been made, served the same purpose of burying out of sight an old and entirely different topography. The deposit of ash, so-called, was much deeper than the northwestern lava, and so larger topographical features were hidden. The course taken by the Gunnison, a course which was determined entirely by the westward slope of the ash plateau, caused the river to flow over a buried mountain of granite, and when the channel was cut down to the granite, the stream was so deeply intrenched that it could not change its course and



Granite Canyon From Tonto Esplanade, West of Bright Angel Trail. The tower of Set is in the distance on the right. It is 1,250 feet from rim rock to river, measuring from surface of the Tonto platform, which is the flat bench on the upper right



A FLAT-TOPPED HILL OR MESA, NEW MEXICO

was compelled to continue excavating in the hard rock along the same line, until it had carved out a gorge 2,000 feet deep in the granite. The "Black Cañon of the Gunnison" is one of the most noted features of Colorado scenery, and owes its existence to the fortunate accident which caused the river to begin its flow directly above the site of the concealed granite mass. Though a tributary of the Gunnison, the Uncompahgre flows parallel with it for a considerable distance. Chance brought the Gunnison to flow over a buried mountain, and gave the Uncompahgre a course over a buried valley, but despite the relative ease of its task the tributary could not cut below the main stream into which it empties and which forms its temporary base level.

A superimposed river of quite a distinct type is the Colorado in the region of its great cañons. The plateau through which the cañons have been cut is composed, at the surface and for 4,000 or 5,000 feet below, of nearly horizontal beds of sedimentary rock, chiefly limestones and sandstones. It is in these strata that the great outer gorge of the cañon has been cut, while the inner gorge is trenched in a mass of very much more ancient, inclined, folded, and crystalline rocks, both igneous and metamorphic, into which the torrential river has cut for a depth of 1,500 feet. The abrupt and striking difference between the outer and the inner gorges is not due altogether to the change in the character of the rock, but also, very probably, to a change of climate. The outer gorge was made when the rainfall was much heavier than now and the climate moister, in consequence of which the atmospheric attack upon the walls of the cañon was more effective and the widening went on much more rapidly.

The five classes of streams that are enumerated in the foregoing pages, the consequent, subsequent, obsequent, antecedent, and superimposed, are not altogether mutually exclusive, and the same stream, without change of course, may, at different stages of its history, be referable now to one class, now to another. What is more remarkable, different parts of the same stream may be properly referred to different classes. This is due to the wonderful changes which a river system undergoes in the course of its development, and to the fact that old river systems are usually made up of a patchwork of streams that were originally independent, but have been brought into connection with one another in the process of adjustment to the rock structure of the drainage basin. Any stream, whatever its mode of origin, will become antecedent, if a movement of the earth's crust, involving the basin of the stream and producing changes of the surface, occurs without changing the course of the stream or causing it to cease its flow. Superimposed streams almost invariably began their career as consequent streams, as their course was determined by the slope of the newer accumulations which formed the surface. It is when they have cut through these newer accumulations and have begun to cut into the underlying and older rocks that they cease to be consequent and become superimposed. The converse of this statement is by no means true, for not all, nor even most, consequent streams are likely to become superimposed through the revelation of a buried topography. The Columbia and Snake Rivers are both superimposed and antecedent, because of the earth movements which have occurred since their establishment without diverting them into new courses.

In addition to the changes and modifications which earth movements occasion in river courses and systems by elevation and depression, there are very far-reaching changes which come about in the course of development and in the process of adjustment to the rock structure, an adjustment which, when time is allowed, becomes so surprisingly close. Remarkable appearances to the contrary notwithstanding, all streams seek out the lines of weakness and everywhere take the path of least resistance to their final destination. In view of what has been described in the foregoing pages in the case of such rivers as those which cross the Appalachian ridges, the Green and the Yampa in their astonishing course through the Uinta Mountains, and the, at first sight, utterly inexplicable cañon of the Gunnison cut through a granite mountain which might, to all appearances, have been so easily avoided, it seems ridiculous to say that streams take the path of least resistance. Yet such is the fact and it invariably happens that, when the history of the topographical changes can be deciphered, the apparently paradoxical character of the river's behavior is seen to be apparent only, and it becomes clear that the course taken by the river is the only one possible under the circumstances. In all cases the key to the stream's behavior is to be found in the changes in the character of the topography since the river began its flow. The topography which was actually present at the time when the river came into existence compelled the course that was taken.

Rivers tend constantly to lengthen their courses by working upstream, the springs in which streams and their tributaries arise are constantly undermining their banks and so working upward and lengthening the streams that flow from them. A spring is merely ground water coming to the surface, or in limestone regions, with many caverns and underground channels, a spring may be the rising of a subterranean stream. This process of lengthening the stream is called "the recession of spring heads" and is, of course, extremely slow, though not unduly so in the geological time scale. This lengthening of the streams, with its consequent shifting of divides, has some very curious results. For instance, two streams that head on opposite sides of a ridge, with their two valleys more or less in line, may each work backward and actually pass each other without meeting, but opening a pass through the ridge. Mountain passes are formed in many ways, but the junction of two properly placed valleys on opposite sides of a ridge by recession of the springs at the head of each valley is one of these ways, and then we have the remarkable result of a continuous valley occupied by two streams flowing in opposite directions and the divide between them almost imperceptible. This also is a not unusual phenomenon produced in a variety of ways, and may occur in valleys of folding, or in rift valleys, according to the original slopes of those valley floors. In the central valley of Montana, between the Big Belt and Little Belt Mountains, the Shields River flows southward to the Yellowstone and the Smith River northward to the Missouri, and the heads of the two streams are quite near together on the flat valley floor, with no conspicuous divide between them.

CHAPTER VII

THE DEVELOPMENT OF RIVERS—*Continued*

THE lengthening of streams and their branches and the consequent shifting of divides have frequently resulted in the very curious process known as "stream capture," or "piracy," by means of which streams or, much more commonly, parts of streams, are diverted to those which are more favorably situated and thus made a part of the more successful system. It is to this process of stream capture that is due the patchwork nature of so many rivers in all parts of the world previously referred to, and a great many anomalies in the courses followed by streams are thus to be explained. The more favorable situation of a stream, as compared with others, a situation which enables it to shift the watershed to its own advantage, may be occasioned in many different ways, according to the special circumstances of each case. The more advantageous situation may be because the stream in question has a shorter course and greater fall; that would give a more rapid current, which, in turn, would make the stream more effective in cutting down its channel and in transporting its load of sediment. The more favorably situated stream may have a course over soft rocks, which are easily and rapidly excavated, while the other stream runs over hard rocks and ledges, which yield but slowly to the wearing action of the water and the sand and gravel which it sets in motion.

There is another circumstance which may give the advantage to one of two streams which, at first, would seem to be very evenly matched; this circumstance is the attitude and arrangement of the stratified rocks of the basin. In regions of inclined beds, for example, the escarpments, formed by the outcropping ledges of the harder rocks, tend to recede in the direction in which the beds are inclined. Such escarpments frequently are the divides between minor streams, and the stream toward which the ledge inclines will be at a disadvantage, because the retreat of the inclined bed narrows the drainage area of that stream, while correspondingly widening the valley of the parallel stream on the other side of the escarpment, and so increasing the volume and velocity and consequent efficiency of that stream. This process of the shifting of divides is, of course, very slow and gradual, but, after a long period of this sort of gradual recession, the actual capture and diversion of part of a stream may be rapidly, even suddenly, effected.

Stream capture, or piracy, may be brought about in a variety of ways. Suppose two streams flowing in more or less parallel courses, but at different levels; the stream flowing at the lower level will give a greater fall and swifter flow to its tributaries, though the stream itself has less fall and slower current. The tributaries of this lower level stream will work upward and lengthen their courses more rapidly, and one of these tributaries will eventually cut its way through the divide and tap the parallel main stream. The stream thus tapped will lose all of its water above the point of junction, because that water is diverted to the capturing tributary and carried off to the main stream which flows at the lower level.

If two streams rise on opposite sides of a watershed and one of them has a much steeper course than the other, it will extend upward more rapidly and ultimately capture the headwaters of the stream on the opposite side of the watershed. This process is exemplified in an interesting way by certain streams of the Catskill Mountains. The Catskills are not a true mountain range, due to folding, but are fragments of a dissected plateau, built up of nearly horizontal strata, though the surface of the table-land has a gentle slope to the westward, while the eastern face is a steep escarpment, descending into the valley of the Hudson. Westward-flowing streams, notably Schoharie Creek, follow the gentle slope of the plateau surface, while the streams that flow eastward from the steep escarpment to the Hudson have a rapid current because of their steep descent. The Kaaters Kill and Plaaters Kill, which are conspicuous among these eastward streams, have, like the others which flow in the easterly direction, made the escarpment face sinuous by cutting recessions for themselves, and have lengthened their courses by extending upstream, capturing and diverting several tributaries of Schoharie Creek. These captured tributaries follow a very curious course; they begin by flowing toward the Schoharie, just as they originally did, but each one makes a sudden, sharp turn, reverses its direction, and flows into the capturing stream. So frequent and characteristic is this sudden bend and reversal of direction in the captured stream, that it is called the "elbow of capture" and, on a good map, one can often identify the captured portions of streams.

An illustration of a somewhat different type is afforded by the Yellowstone Lake and River. The Lake originally discharged its waters southwestward to the Snake River and thus into the Columbia River and the Pacific Ocean. The abandoned channel, which was occupied by the outlet of the lake, is still in perfect preservation and may be readily traced. At that time, the Yellowstone River was a small stream which arose considerably to the north of the lake and flowed northward to join the Missouri and thus was a part, as it still is, of the Atlantic drainage. The young river was favorably situated for establishing a steep gradient, for its course lay across the lofty plateau, though its elevation has probably been increased since that time, which is built up of successive flows of a comparatively soft and deeply decomposed lava. Extending upward by the recession of its springhead, the stream eventually reached the lake and tapped it and, forming an outlet at a lower level than the old one on the south side of the lake which led to the Snake River, diverted the waters of the lake to the Missouri River. Not only was the direction of the lake's discharge thus reversed and changed from south to north, but the position of the great continental divide was shifted, putting the lake on the Atlantic side of the watershed, whereas it had before been on the Pacific side. Several streams now enter the lake from the south, which originally was the outlet side.

Many of the rivers which cross the Appalachian ranges exhibit a great number of cases of stream capture by a method which is quite different from those previously described. These Appalachian rivers, it will be remembered, are transverse, that is to say, they flow across the edges of the outcropping beds of rock, and have cut gorges, or "water gaps," through the particularly hard and resistant rocks. Along the lines of outcrop of the softer rocks, longitudinal valleys have been excavated, and these valleys are, very generally, occupied by streams which are tributaries of the main, transverse rivers. If two of these transverse streams, following approximately parallel courses and separated by no great distance, are of very different size and volume, the larger stream will deepen its channel through the harder rocks at a correspondingly faster rate and thus give to its tributaries a steeper fall, swifter current, and more efficient work of excavation of the channel and extension in length by the process of springhead recession. One or other of these tributaries of the larger stream will extend its length until it effects an entrance into the drainage basin of the smaller one. If the longitudinal valley containing the tributary of the larger stream also contains a branch of the smaller one, the capture will be effected by means of this branch, which will be diverted into the tributary of the larger stream, because that tributary has already cut its channel down to a lower level. Not only will the tapped branch of the smaller main stream have its direction of flow reversed, but it will take with it the waters of the smaller main stream above the point of junction, because the new course affords the greatest fall and most direct course. Should the smaller main stream have no branch in that particular valley, the lengthening tributary of the larger stream will eventually reach and divert the upper course of the smaller river. A stream, of which the upper portion has been captured and diverted to another, is said to be "beheaded," a process very frequently exemplified in Appalachian rivers that pursue a transverse course across the mountain ridges.

In regions of folded rocks, which have been crumpled into a series of upward and downward bends and curves, the process of stream adjustment to rock structure may become extremely complicated and it would serve no useful purpose to enter into a description of these complex processes, especially as the general principle involved is the same as that exemplified in the cases already described. Indeed, the general principle is the same in all cases, whether simple or complex. The more favorably situated stream, by extending its length and shifting its divide, will cut off more or less of some stream which is not so favorably situated and divert its waters to the capturing stream.

The foregoing account of stream capture, which is the merest outline sketch, may well seem altogether fanciful to the casual reader; an amusing game played with a map and an active imagination. Such a feeling of unreality, however, is due to the natural, though mistaken, notion, that the features of the landscape, which have not perceptibly changed in our time or our fathers' time, are essentially immutable. Besides, we are apt to think of rivers as canals, deriving all their supply of water from their sources and their tributaries, as is true of certain exceptional rivers, such as the Nile and the Colorado. Could a branch of the Congo tap and divert the Nile below the junction of its two main branches, the long course of the river through Egypt would undoubtedly be abandoned and that country would speedily revert to the desert. If streams were like pipes leading from a reservoir, in which all the water comes from one end, beheading the stream would lead to the abandonment of the channel below the point of tapping. Sometimes considerable stretches of the tapped stream actually are abandoned.

In a climate of normal rainfall, distributed throughout the year, and without a long dry season, a river is fed by countless springs and small branches, so that almost any considerable part of its course is capable of independent existence. Such a stream can well survive beheading or the capture and diversion of many of its tributaries.

To one who is not content with maps, but studies the phenomena of river development and adjustment at first hand and in the field, soon comes the conviction that stream capture is not a mere fancy, but a very real process. The many dry watercourses and parts of channels forsaken by their streams remain to testify to the actuality of these changes. Naturally, such features of the land surface do not persist from any very great geological antiquity, for the destructive agencies attack them, as they do all parts of the land, and remove them in a relatively short time. But great numbers of abandoned channels, abandoned not only because of stream capture, but also because of change of climate or other accident, still remain from the later portions of the earth's recorded history.

All of the preceding cases of alteration in the course of streams took place in prehistoric times and were not witnessed or recorded by any human being, but are inferred from the observations which can still be made. However, various modifications of drainage systems have taken place within historic times and have been credibly recorded; some of these modifications are due to artificial interference, others are entirely natural. The Hoang-ho, one of the great rivers of China, which is called "China's Sorrow," has frequently shifted its lower course, owing to the raising of the river bed by its own deposits. Breaking out of its banks, the river has caused most disastrous floods, with appalling loss of life and destruction of property. The oldest place of discharge into the Yellow Sea known to history is the northernmost one, at 39 degrees 40 minutes N. lat. From the thirteenth century to 1851 the mouth was more than five degrees farther south in 34 degrees N. lat. In the years 1851-53 it turned again to the north, in 1887 broke out again to the south, and in 1889 was artificially compelled to take its former course.

Changes in the courses of some of the French rivers can be determined from the evidence of old documents and maps. In the Department of the Jura the Vallière receives four tributaries from the east, the Somme, the Dérobé, the Roi, and the Sonette. In 1658 only the last named emptied directly into the Vallière, for at that time the Somme was still a branch of the Sonette, but had become independent by 1748 and sent out an arm, which eventually became the separate tributary, the Roi. The first appearance of the Dérobé is on a map of 1841, in which it is shown as a branch of the Somme, from which it later separated and became a direct tributary of the Vallière, as it still is. Even making every allowance for inaccuracy of the old maps, this is a remarkable series of changes to have taken place in so short a time.

Delta growth may bring about the junction of streams which originally were independent. It was not until after the eighth century B. C. that the Euphrates and the Tigris united to form the river which is now known as the Shat-el-Arab. The Seihun and Jihar are two streams which empty separately into the Gulf of Alexandretta (Asia Minor) and, at present, the distance between their mouths is nearly forty miles. Since the fifth century B. C. they have three times united and three times separated. The Danube has built up a delta at its mouth in the Black Sea, and the growth of this delta has converted the Pruth, which once discharged directly into the sea, into a tributary of the Danube.

What slight causes may, under favorable circumstances, produce considerable and lasting effects in the way of stream diversion is shown by a modern example that took place in Ohio. Raccoon Creek, which originally flowed westward to Pleasant Run, was forced to take an easterly direction and join Rush Creek by the building of a dam and mill race, and this change has persisted in spite of the removal of the dam and the race.

The Rhine has passed through a remarkable series of changes, having, at different times, sent its waters to the Mediterranean, the Black Sea and, as at present, the North Sea. At a period quite late in geological history, but before the appearance of man, at least in Europe, the Rhine was connected with the Doubs, which is a tributary of the Saone, and the latter reaches the Mediterranean through the Rhone. At another period we find the upper Rhine and the Lake of Geneva forming a part of the Danube system. The formation of the rift valley by parallel faults, first between the Vosges and the Black Forest, and then from Bingen to Bonn, opened up a way to the north. Besides these major changes, of course, there were a great many minor ones; for example, the Biberthal in Switzerland was once occupied by the Rhine and it formerly flowed directly from Schaffhausen to Waldshut; this latter abandoned channel is now made use of to carry the railway line. Near its end in the North Sea the Rhine has built up a delta; indeed, the Netherlands are chiefly made up of the deltas of the Rhine and the Maas, as the Meuse is called in Holland. In this area of delta deposits the rivers have made countless shifts and cross connections within historic times.

The Tennessee River, which was once connected with the Coosa and the Alabama, formerly flowed directly into the Gulf of Mexico. A long, complicated series of events built up the present river out of a patchwork of many streams, and has given it the remarkable northward sweep to the Ohio. It has thus been drawn into the system of the Mississippi, of which it was originally quite independent.

In the course of the development of river systems and the extension of tributaries, rivers may come very close together and even become connected without, however, effecting a capture. No doubt, great changes are, in these cases, in course of preparation, but they have not yet occurred. In collecting for the American Museum of Natural History, H. Lang traversed much of the Belgian Congo; he says: "To the north and northeast some of the swamps forming the sources of the affluents of the Congo and the Nile are separated by only low undulations, in some places no more than fifteen feet wide. In years of extra heavy rainfall, the two river systems may thus be connected, especially as here the rise of the waters is often surprisingly rapid. As a result there are a large number of species of fishes common to both water courses." One of the best known examples of a connection between different river systems is to be seen in South America. The Cassiquiare, a branch of the Orinoco, is connected with the Rio Negro, which is a tributary of the Amazon. Far to the south, a somewhat similar relation exists between the headwaters of the Madeira, the principal southern tributary of the Amazon, and those of the Paraguay, a branch of the Parana which, with the Uruguay, forms the great Rio de la Plata; they are almost in contact and, in seasons of very high water, they are actually connected. It is thus possible to travel by canoe, though with many portages around rapids in the upper waters of the Madeira, from the mouth of the Orinoco to the mouth of the Rio de la Plata, a distance exceeding 3,000 miles in a straight line, and very much more than that by the watercourses.

When a drainage system has become thoroughly mature, it is completely adjusted to the rock structure of its drainage basin. After such complete adjustment, however, a reelevation of the region may necessitate a new and entirely different adjustment, by changing the relations of the hard and soft rocks to the new base level. If an accurate model be made of a region of inclined or folded strata, reproducing the actual arrangement of the beds of rock, and then a series of horizontal cuts be made through the model at different levels, one is often surprised to see how different are the mutual relations of the strata at these different levels. In areas of horizontal strata entirely different beds may be encountered at the various levels. A land surface which has passed through repeated geographical cycles, will have suffered many revolutions of its drainage systems.

The term "accidents," as applied to rivers, is used to denote the interruptions which interfere with, or, it may be, entirely put an end to, the normal development of a river system. Changes of elevation, whether upward or downward, may bring about the normal development of the cycle, may interrupt it, or put an end to it. Likewise changes of climate often have a profound effect upon the rivers. Since the close of the Glacial Epoch the climate of the western part of the United States has become very much drier than it was before; as a result of this desiccation, many streams have completely disappeared and numbers of water-excavated cañons have no stream in them now. The very extensive fresh-water lakes, which once existed in the Great Basin and had an outlet northward to the Snake River and thence to the Columbia, have either been dried up, or greatly reduced in size and converted into salt or soda or borax lakes. The streams all either end in such lakes or lose themselves in the desert sands, and now no water flows out from the land-locked Great Basin. This climatic "accident" has greatly interfered with the development of the rivers of the region, cutting them off from the sea and altogether destroying a great many of them.

Another type of "accident" is that caused by the great lava flows, such as that of the northwestern States. These floods of molten rock have filled up all the old valleys, obliterating the drainage systems and compelling the establishment of new systems which have no relation whatever to the old.

The importance of a river system is determined, first of all, by the climate of the region which it drains and also, in very large degree, by the topography of its drainage basin. The mere length of a river does not establish its rank; rather is it a question of the drainage area involved. The Amazon, which is the largest of all rivers in the sense that it discharges by far the greatest amount of water, is shorter by 600 miles than the Nile, and is much exceeded in length by the combined Mississippi-Missouri system, but its drainage basin is much larger and the amount of water carried is incomparably greater. The amount of water is chiefly a matter of climate; the Amazon is so great because of the extremely heavy rainfall of tropical Brazil and the tremendous precipitation upon the eastern side of the Andes. No part of the Amazon basin has a dry climate, while the western half of the Mississippi basin is semiarid and, for a great part of its length, the Nile flows through a desert, receiving no tributary for more than 1,000 miles.

If on a map, with the north pole in the center and showing all the great land masses, except Australia and Antarctica, the line of main watershed between the Atlantic and Pacific be drawn, it will be continuous, with the single interruption at Bering Strait, and will be seen to follow an extremely asymmetrical course; in drawing this line, the Indian Ocean is regarded as part of the Pacific, and the Arctic as belonging to the Atlantic. To a very remarkable degree, the Atlantic slope of the lands preponderates over the Pacific slope and, consequently, nearly all the great rivers of the world belong to the Atlantic drainage. Almost the only exceptions to this rule are the rivers of eastern and southern Asia. In the Americas the main watershed follows the high mountain ranges near the western margin of the continents from Cape Horn to Bering Strait; on the Asiatic side of the strait, the line passes southwestward to Tibet and thence westward almost to the Mediterranean. In Africa the line passes down near the east coast, until Natal is reached, when it swings over almost to the Atlantic coast. Each of the continents has more or less extensive areas which have no outlet to the sea; according to Supan, the percentages of the different continents which are covered by these landlocked basins are as follows; Australia, 53.9; Asia, 30.6; Europe 20.4; Africa, 30.5; North America, 5.0; South America, 1.7. Disregarding these dry basins without outlet to the sea, the proportions of the Atlantic and Pacific slopes are as follows, in millions of square kilometers. Europe is entirely Atlantic; in Asia the Atlantic slope is 12, the Pacific nearly 17; in Africa the Atlantic drainage area is 14.9, the Pacific 5.4; in North America the Atlantic slope is 14.4, the Pacific 4.5; in South America the disproportion is quite remarkable, Atlantic 16.3 and Pacific 1. The only one of the continents enumerated in which Pacific-Indian drainage area exceeds the Atlantic-Arctic, is Asia. The noteworthy preponderance of the Atlantic area has had a profound effect upon the course of history.

The rivers of North America form a vast system of closely connected and navigable waterways, a system which played a most important and significant rôle, first, in the exploration and opening up of the continent and, secondly, in the development of its internal communications and, thirdly, as a source of power for manufacturing purposes. In these latter respects the value of rivers has been subject to great fluctuations and the end is not yet. The building of railroads greatly diminished the importance of the river as a means of transportation, and the coal, which was made cheap by low freight rates on the railroads, nearly put an end to the use of water power in all but the more primitive and local kinds of manufacturing. Of late years the pendulum has begun to swing in the opposite direction.

The rivers which drain the great northern plains and basins and empty into the Arctic Ocean have never been of great importance in navigation, save for the canoe of the trapper and the voyageur, though the Yukon has been the principal means of transportation in Alaska. The St. Lawrence brought the early French colonists into the heart of the continent, around the northern end of the Appalachian mountain system, which so long acted as a barrier to the English colonists, confining them to the relatively narrow belt along the Atlantic coast. The French colonial policy, under Louis XIV and his successors, was, as can now be readily seen, fatally mistaken from the economic point of view; the French Canadians lived by the fur trade, and agriculture was of only secondary importance. The rivers were the only means of communication, and almost every house in Canada was on the bank of a stream. Because of their favorable position the hardy Frenchmen, fur traders, trappers, or Jesuit missionaries, spread themselves with great rapidity over the interior of North America and took possession of the country by building military and trading posts at all strategic points. The means by which this extraordinarily rapid spread was accomplished was, primarily, the birch-bark canoe, which could shoot the rapids and was easily handled at the portages. Very many streams which flow into the Great Lakes have their headwaters separated by very short spaces from the heads of streams which lead to the Mississippi. That river, it is true, was discovered by the Spaniard De Soto, in 1541, possibly even in 1519 by De Pineda, but the discovery led to nothing; and not until the journey of Joliet and Père Marquette in 1673, down the river from the mouth of the Wisconsin to the junction of the Arkansas, was the Mississippi revealed to Europe, and in 1682 La Salle descended to the Gulf of Mexico and, under the name of Louisiana, took possession of the whole Mississippi Valley for the king of France; the founding of New Orleans followed in 1718. From the mouth of the St. Lawrence to that of the Mississippi, the whole country seemed to be securely in the grasp of the French.

The French made the capital mistake of spreading themselves too thin and attempting to hold far too much territory with their limited numbers. When the inevitable grapple between the French and English colonists was seriously precipitated, the much more numerous English, who had developed compact agricultural communities, necessarily won the contest, especially as the British fleet commanded the sea and made the sending of reenforcements from France difficult and precarious. When all of the continent east of the Mississippi River had been brought under British rule, the colonists poured over the Appalachian barrier, and after the Louisiana purchase of 1803 they soon established themselves on the western shore of the great river.

The whole future of the country after the Revolution trembled in the balance during the days when the Spaniards held the mouth of the Mississippi and arbitrarily closed it to American traders whenever they felt inclined. The thrifty and energetic communities, which were rising west of the mountains, were threatened with strangulation in their birth, and many were the propositions made to separate from the seaboard States and either become an independent nation friendly to Spain, or to unite once more with Great Britain. The Louisiana purchase and the acquisition of New Orleans removed these dangers, for it may be questioned whether Burr's conspiracy was ever a serious peril to the nation.

Till the outbreak of the Civil War, the western rivers were the great avenues of transportation by flatboat and steamer. As early as 1834, there were as many as 230 steamboats on the Mississippi. It would require a volume fully to explain the part which rivers played in the development of the Middle West. The population of the Mississippi Valley, which had been 2,500,000 in 1820, exceeded 14,000,000 in 1861, but long before the invention of the steamboat the importance of American rivers had made itself apparent from the beginning of European settlement. A series of maps, showing the growth of population in the English colonies along the Atlantic seaboard, will make plain the way in which rivers were utilized to penetrate the interior, how settlements were made along the rivers and followed them up. The rivers and the sea were the chief highways of travel and transportation, as roads were few and bad. However, the rivers of the Atlantic seaboard were not navigable very far inland and, even in canoes, did not carry the explorer far into the interior of the country. In all the British colonies there was but one area where the flank of the Appalachian barrier could be conveniently turned, and that was the valley of the Mohawk, which flows into the Hudson from the west. The Dutch had very early extended their settlements up the Hudson to Albany and westward to Schenectady and, as a result of their war with Holland in 1665, the English took over these regions. The low-grade pass formed by the Mohawk Valley retains its importance to this day, as is clearly shown by the fact that the Erie Canal and the New York Central and West Shore Railroads, are all compelled to follow this route. In colonial times, however, the British could not make extensive use of this open road to the West because the land was occupied and jealously held by the formidable confederacy of the Iroquois who, though the allies of the British and enemies of the French, as they were afterward of the Americans, blocked the way to western emigration. The mountain barrier was crossed, though with difficulty, far to the south in Pennsylvania and Virginia and the Carolinas.

In the Civil War the western rivers played a dominating rôle in the movement of troops and the course of campaigns. Fleets of armored gunboats were established on these rivers by the navy and afforded invaluable support to the work of the army. The genius of Lee has led historians to attribute undue importance to the Virginia campaigns; aside from the effects of the blockade, the war was won and lost in the West, and there the importance of the rivers was most obvious. The events of 1861-2 had reduced the Confederate hold on the Mississippi to Vicksburg and Port Hudson, and when these strongholds fell in 1863, the Confederacy was cut in two and its fate decided.

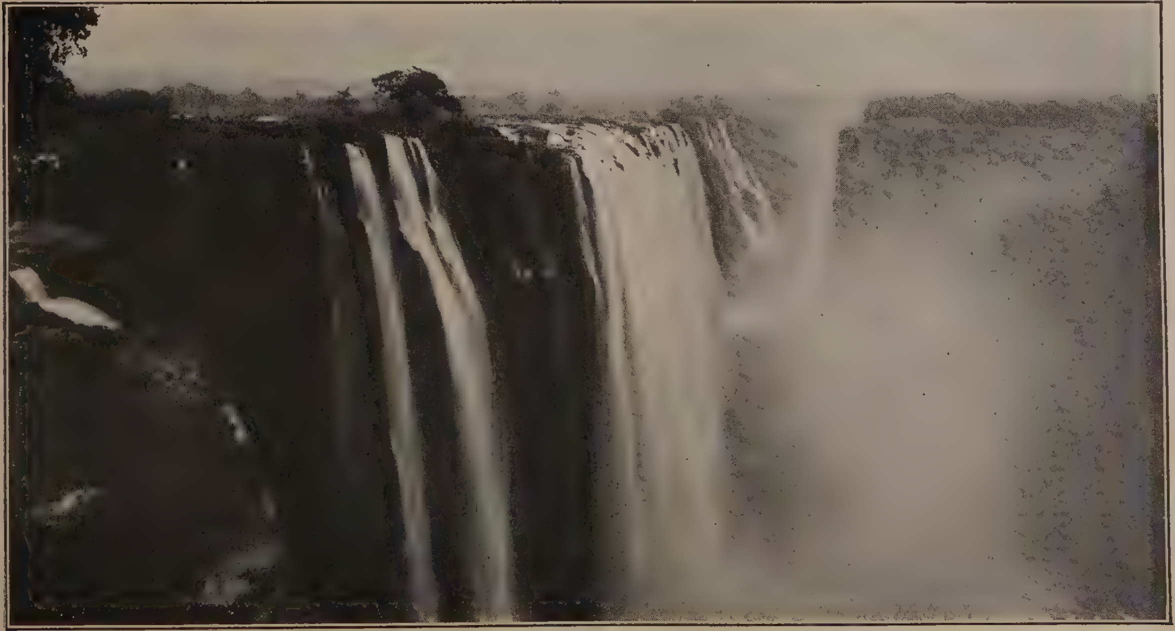
On the Pacific side, only two great rivers enter the sea within the limits of the United States, excluding Alaska; the Colorado in the south and the Columbia in the north. The former is of no importance as a navigable stream; the Columbia and its tributary, the Willamette (on which Portland stands) are navigable but a short distance from the sea. Before the building of railroads, emigration to the Pacific coast was carried on across the Great Plains and the Rocky Mountains chiefly by means of the lumbering, canvas-covered wagon known as the "prairie schooner," for only the Missouri River could be used for part of the journey by steamboat.

South of the United States, the rivers of Mexico and Central America are of small importance. The peculiar conformation of Mexico, a high plateau shut in by mountains and having a semiarid climate, with narrow lowlands along the coasts, is such as to prevent the formation of large drainage basins. Central America has very heavy rainfall on the eastern side of the mountains, but the land is too narrow for large rivers. In connection with the Panama Canal, the little Chagres has risen to great importance, for it supplies the water for Gatun Lake, which is the summit level, and much the longest part of the canal is filled with fresh water from the Chagres. The little stream is subject to sudden and violent floods, but Gatun Lake acts as a regulator and prevents these floods from becoming dangerous by spreading them over a large area.

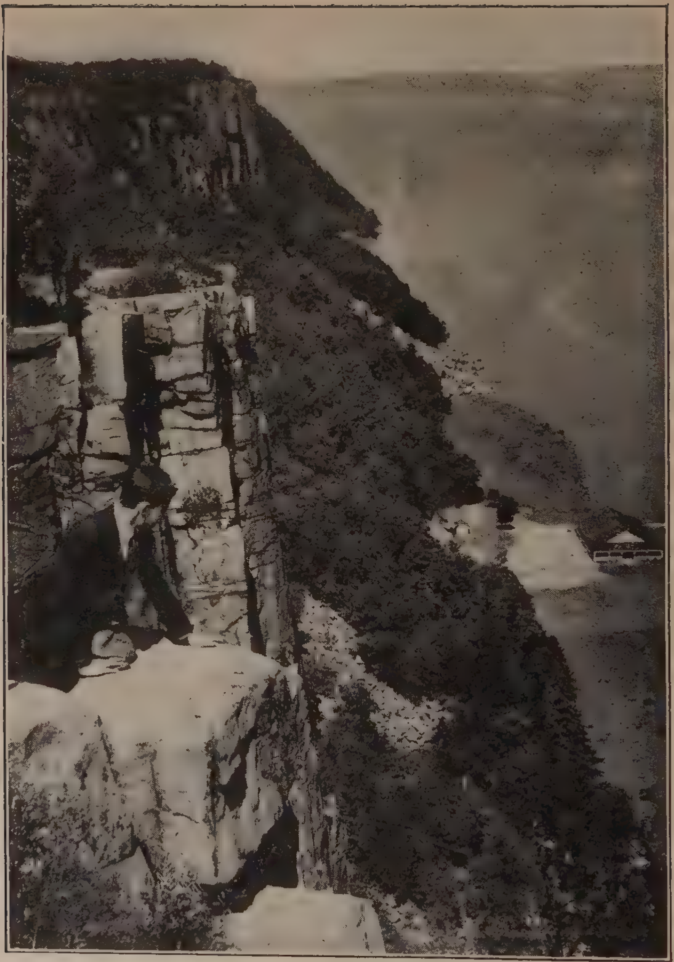
Asia, though by far the largest of the continents, does not have correspondingly large rivers, chiefly because of its topography. Not that Asia has not great rivers; the Siberian streams, notably the Ob, the rivers of India (such as the Ganges), Burma and Siam, are very large, but they have neither the length, nor the volume that are proportionate to the immensity of the continent. The great rivers of China are still as they have been for thousands of years, busy arteries of traffic, and afford a living and a home to a dense population.

In size, Africa is the second of the continents, but has surprisingly few navigable rivers, which is partly due to climatic, but more to topographical factors. The interior of Africa, south of the Sahara, is a plateau from 2,000 to 5,000 feet high, with narrow and much lower coastal strips. From the borders of the plateau many streams with short courses run to the sea, but these are of small volume and have little importance. The great rivers of Africa all rise in the uplands and, in descending to the sea level, form long series of rapids and waterfalls which effectually block navigation. This paucity of navigable streams is one of the reasons why Africa so long remained the "dark continent" and has been opened up by European exploration only within the last half century. The first European who crossed central Africa from sea to sea was David Livingstone in 1853-56. North Africa has been known to civilized man for ages, and the civilization of Egypt goes back to the very dawn of history. There can be little doubt of the truth of the statement made by Herodotus, that Phœnician sailors in Egyptian employ circumnavigated Africa, but the coasts, south of the Sahara, and south Africa were first really made known by the Portuguese in the fifteenth century.

There is an astonishing contrast between North America and Africa in the rapidity with which they were explored. In a little more than two centuries after the discovery of North America, the Spaniards,



VICTORIA FALLS (ZAMBEZI RIVER, SOUTH AFRICA), LOOKING EAST FROM LIVINGSTON ISLAND



PALISADES OF THE HUDSON RIVER, SHOWING FRAGMENTS THAT HAVE FALLEN FROM THE CLIFFS the French, and the English had traversed nearly the whole of it, while for thousands of years much the greater part of Africa remained inaccessible and unknown.

Tropical Africa, particularly on the western side, where the rainfall is heavy, is extremely unhealthy, and white men have rapidly succumbed to its malignant forms of malaria, but a greater obstacle in the way of the explorer was found in the tsetse flies, one species of which causes sleeping sickness in man, and of others the bite is speedily fatal to domestic animals. For these and other reasons, the exploration of tropical Africa has been performed on foot, with long lines of porters to carry supplies.

Australia has peculiar river systems. Except on the southwestern and the western portion of the south coast, the shore belt has numerous short and swift streams, but few that are navigable for any considerable distance inland. The great interior basin of the continent is very dry, and its central and western parts are vast deserts without streams. The Murray, with its principal tributary, the Darling, is navigable for long distances in the wet season. With one or two exceptions, Australian rivers are channels of rain water, which in the interior go dry or become lines of pools in dry seasons, the rarity of springs west of the eastern belt of mountains being very remarkable. Even more remarkable is the small proportion of the rainfall which is discharged into the sea by the streams. The Darling carries only 10 per cent of the water which falls upon its drainage area, and it is believed that the network of buried channels which lies beneath the great alluvial plain of the interior absorbs most of the 90 per cent remaining.

CHAPTER VIII

LAKES—PLAINS.

FROM the point of view of geological time, lakes are but ephemeral features of the land and, sooner or later, are bound to disappear, either by means of the filling of their basins with solid material, or by the cutting down of the outlet through the barrier which acts as a dam and ponds back the water, or by both methods in combination. An instructive illustration of the manner in which lakes are drained and at the same time of the way in which a stream will rapidly excavate its channel when the volume of its water and the velocity of its current are greatly increased, is afforded by Lake Ilopango in Salvador, one of the Central American republics. The lake, which is surrounded on all sides by steep mountains and therefore has no room to expand horizontally, rose four feet in the first days of January, 1880, probably because of volcanic disturbances which gave birth to new islands in the middle of the lake. The outlet stream, called the Jibon, which was, before the disturbances began, very shallow and only twenty feet wide, was converted into a furious torrent. This great increase in volume and velocity correspondingly increased the erosive power of the current, which cut down its channel through the volcanic rocks to a depth of thirty-five feet. Such deepening of the outlet channel, in turn, permanently lowered the level of the lake more than thirty-four feet. This is, of course, an unusual accident, but it merely hastened the inevitable draining of the lake.

Many lakes have their bottoms well below sea level, and, in such cases, the outlet stream, if it eventually reaches the sea, could not cut below its base level and therefore could not completely drain the lake. The salt lakes of desert basins, which have no outlet, may persist for relatively very long times, so long as the climate remains substantially unchanged and streams continue to flow into the basin, but not out of it. Unless those streams are so small that they are dried up by evaporation and absorption in the desert sands, they must end in lakes. Such lakes may shift their position and change their shape, as is known to be true of some lakes in the central Asiatic basins, but they continue to exist.

Large-scale maps on which all the lakes, large and small, are indicated, show a very extraordinary difference between various regions with regard to the number of the lakes which they possess, and a comparative study of these lands leads to the conclusion that lakes are numerous in regions of youthful topography, unless there is some particular reason for their absence, while they are few in regions of completely mature or old topography. Florida has an immense number of lakes, estimated at no less than 30,000; most of these are, of course, small and they are arranged in series down the central part of the peninsula, which is almost entirely composed of limestone rock and therefore, like all such regions, has a great network of underground channels and subterranean streams. The lakes occupy, for the most part, sink holes and depressions, which have been formed in the limestone by solution. Often two or more lakes have underground connections and their levels fluctuate together. Very much the largest of the Florida lakes is Lake Okeechobee, which covers an area of 1,250 square miles, but is rarely more than fifteen feet deep. The peninsula of Florida is, geologically speaking, new land and, though low-lying and having few points more than 300 feet above the sea, it has a youthful topography, not one from which the formerly existing relief has been worn away by erosion. Florida is the only part of the southern United States where lakes are numerous.

The great terminal moraine, which has been traced across the continent from Nantucket to British Columbia as a sinuous line, marks the limit of the last extension of the continental ice sheet in the Glacial Epoch. On the two sides of that line there is the greatest possible contrast in regard to the number of lakes; south of it, the lakes are few and small; north of it, they are countless and some are the largest of all fresh-water seas. Minnesota alone has 10,000 lakes, it is estimated, and Wisconsin, Canada, New York, and New England, have lakes in such numbers that they have not been counted. The same contrast may be observed in Europe; in the regions which were ice-swept in the Glacial Epoch, Ireland, Scotland and the north of England, Scandinavia, and Finland, have innumerable lakes, many of them famous for their beauty. Another part of Europe which was deeply buried under vast streams of flowing ice, was the Alps, the glaciers extending far out over the surrounding lowlands. The lakes of Switzerland and northern Italy, and the Tyrol and the Bavarian highlands are among the most beautiful of the world.

Evidently, there is some connection between lakes and glaciation: so much is admitted by all observers, but there is much debate among geographers and geologists as to just what that connection is. The difference of opinion arises from the different views held with regard to the effectiveness of glacial erosion, some writers attributing to flowing ice a much greater power of cutting into solid rock than do others. Of course, no one imagines that only regions which have been glaciated in relatively recent times can have numerous lakes; Florida shows that that cannot be true. What Florida has in common with the glaciated regions is a youthful topography, nearly always favorable to the formation of lakes, which are gradually filled up or drained, as the cycle of geographical development advances from youthfulness to maturity.

The lakes of glaciated regions are of several types, if classified according to the manner in which they were formed; some of them are relatively short-lived, others comparatively permanent. Ice-dammed lakes, such as are formed when an advancing glacier blocks the mouth of a valley, usually last but a short time, but during the Glacial Epoch, when a wall of ice extended across the continent, the northward flowing drainage was dammed back into some very large lakes, which endured for a long time, as is indicated by deposits laid down in them. One such lake, Lake Agassiz, covered large areas of Manitoba and Minnesota, and its floor is the flat plain, across which flows the Red River of the North. The Great Lakes had a most complicated history during the Glacial Epoch, shifting in size, position, and direction of overflow, as the ice front changed in the course of its long retreat. This history is being reconstructed largely from a study of the various lines of abandoned beach.

Far more enduring are the lakes which are formed behind dams built up in various and very numerous ways. The lateral moraine (i. e., the mass of bowlders, sand, earth, and débris of all sizes which is carried on the top of the ice along its sides) of a vanished glacier may block a tributary side valley and convert the stream flowing in it into a lake. The main valley may be similarly dammed by the terminal moraine of the glacier which once filled it. These morainic dams, though composed of loose, unconsolidated masses, are surprisingly durable. Valleys may be blocked in other ways than by glacial débris. In 1714 and 1749, two peaks of the Diablerets, in the Bernese Oberland of Switzerland, fell into the valley and produced the three lakes of Derborence, which still persist.

Streams flowing into a lake form deltas at their mouths, and the growth of the delta may cut the lake into two parts. The most celebrated case of this sort is at Interlaken in Switzerland, where two lakes, Thun and Brienz, have been separated by a delta. A delta would seem also to be the cause of Lake Pepin, which is a widened portion of the upper Mississippi between Wisconsin and Minnesota. The Chippewa River has brought down great quantities of débris and built a delta by depositing more material than the main river can carry away, thus establishing a partial dam.

Another type of lake, especially frequent in glaciated regions, is the rock basin, in which the bottom and sides are of solid rock in place, not piled-up dams and barriers. It is the question of how the rock basins are formed and how they are related to glacial erosion that has called forth so much discussion. Lakes Seneca and Cayuga, the larger of the elongate "finger lakes" of central New York, occupy rock basins. Some rock basins have, to all appearances at least, been produced by excavation, others by earth movements, warping and tilting of the land. The Great Lakes are apparently due to the combination of many causes, in which river and glacial erosion and tilting of the land surface have all been involved. The violent earthquakes which shook the Mississippi Valley in 1811 and 1812 resulted in the formation of lakes in Missouri and Tennessee, as did the earthquake of 1868 in Ecuador. The Great Rift Valley of eastern Africa and Asia Minor has many lakes, most of them without outlets. Lake basins are also formed by single fault scarps, which act as dams, as in Lake Abert, in eastern Oregon. The vast depression in which lie the Caspian and Aral Seas, is likewise due to movements of the earth's crust and has no connection with the work of glaciers. A curious type is the crater lake, which is formed in the crater of a dormant or extinct volcano.

Finally, may be mentioned those lakes which are portions of the sea, cut off and gradually freshened by the influx of river water. The lakes near New Orleans, such as Lake Pontchartrain, have thus been separated from the Gulf by the irregular advance of the Mississippi delta, and within historic times several instances have been observed of the conversion of a shore bay into a true lake by the growth of a delta, which closes the mouth of the bay.

In size, lakes vary from small ponds to great inland seas. By far the largest of all is the Caspian Sea, of southeastern Europe, which has an area of 161,381 square miles, five times the size of Lake Superior, which comes next in order, and nearly as large as all Sweden. After Lake Superior (32,000 square miles) is a group of four lakes, the Victoria Nyanza, Sea of Aral, Lakes Michigan and Huron, which range from 23,000 to 26,000 square miles. These are all exceptionally large lakes, the continuous series in descending size begins with Lake Tanganyika, in central Africa (12,700 square miles) from which it ranges down to small ponds.

There is much the same variation in depth as in superficial area; the deepest lake yet sounded is the Siberian Lake Baikal, which has depths exceeding 5,000 feet, and next to this is the Caspian, with a maximum depth of more than 3,000 feet. The Great Lakes of the St. Lawrence basin are not very deep, and are surpassed in this respect by many much smaller bodies of water; the deepest of them, Lake Superior, is hardly more than 1,000 feet in depth. As already pointed out, very many lakes in all parts of the world have their bottoms descending well below sea level, sometimes far below; we also find many depressions, but partially, or not at all, occupied by lakes, which descend below sea level. Whether the depression is dry or filled with water, or partly filled, is entirely a question of climate, and extensive climatic changes are registered by the fluctuation of the water level in the depressions. Those that have no lakes in them are in deserts. Death Valley and Salton Sink in California are below sea level, and if they were in a moist climate would undoubtedly be full of water. The

Sink, which is 250 feet below the sea, sometimes became a temporary lake or playa, as it did in 1891 and 1893, and in 1905 the Colorado River broke through and began to fill the Sink and convert it into the "Salton Sea," threatening to overwhelm and destroy great areas of valuable, irrigated farmland. Two years' work was required to bring the river back to its channel and close the breach which it had made. Considerable areas in the Sahara are below sea level, and the late Count Ferdinand de Lesseps, famous as the builder of the Suez Canal, proposed to connect these depressions with the sea and thus ameliorate the climate. The basin of the Caspian Sea is far larger than the lake itself, which occupies only the deepest part of the basin, and there is abundant evidence to prove that the basin was once filled and connected with the Black Sea and the Mediterranean.

There is the same variety in altitude above the sea level among lakes as in all other features. The lowest one yet measured is the Dead Sea, the surface of which is nearly 1,300 feet below that of the Mediterranean. At the other extreme are the numerous lakes of the Tibetan plateau, which has an average height of 16,500 feet. Lake Titicaca in Bolivia has a surface altitude of 12,545 feet, an area of 5,000 square miles, and a maximum depth of 700 feet. In the United States Yellowstone Lake is 7,741 feet above the sea.

The preceding, somewhat informal, classification of lakes is a genetic one and arranges lakes according to the manner in which their basins have been formed, whether by damming, by excavation, or by earth movements. There is another distinction which is of much significance, that into fresh and salt lakes. *Saline* is a better term to include all the lakes whose waters are highly charged with dissolved substances; most saline lakes, though by no means all, are salt. Soda lakes, borax lakes, potash lakes, are instances of lakes which are saline, but not salt. Saline, and especially salt, lakes are characteristic of arid regions, where evaporation is much in excess of rainfall. Saline lakes have no outlet, the water brought by tributary streams being disposed of by evaporation.

The water of springs and rivers always contains dissolved solids, but usually in such small proportions that they are not perceptible to the taste. Just what dissolved substances the water of a given stream will contain, is determined by the soils and rocks which are traversed by the waters of that stream. When the water evaporates from the surface of a lake, the dissolved materials remain behind, and the longer the time that this process continues, the stronger does the solution of dissolved substances in the lake become. Common salt is one of the most widely diffused of compounds and almost all natural waters contain it, but other substances may be present in larger quantities. On the west side of the Great Basin, the saline lakes contain soda (sodium carbonate) or borax (sodium biborate, on the east side is the Great Salt Lake. The Sea of Aral, which lies to the eastward of the Caspian Sea and within the confines of Asia, is remarkable for its shallowness, having an average depth of only fifty feet, although in area it is the fourth of the world's lakes. Its salinity is low, much less than that of the ocean, and yet its waters were formerly at least fifty feet above their present level. The Caspian also has a low degree of salinity, averaging less than one-half that of the ocean; in the northern portion of the sea where the rivers, especially the great Volga, flow in, the surface waters are drinkable, but the gulfs from the eastern and southeastern side, which are in the dry, hot deserts, have very rapid evaporation and the water is a dense brine. The low degree of salinity in the Caspian and the Aral is attributed to the relatively short time since these lakes had outlets. The extreme of salinity is reached in the almost saturated brine of the Dead Sea.

Great Salt Lake is the remnant of a very large body of water, almost two-thirds as large as Lake Superior, which was fresh and had an outlet northward to the Snake River and thence to the Columbia. This ancient lake goes back to the Glacial Epoch, when the general lowering of temperature brought the rain belt far to the south of its present position. The traveler from Ogden to Salt Lake City can hardly fail to notice, on the left side of the railway, very conspicuous parallel lines across the face of the Wasatch Mountains, which enter every valley and follow the windings and sinuosities of the mountains like the contour lines on a map. When examined on the spot, these parallel lines immediately reveal themselves as beaches, which record the changing water levels of the ancient, fresh-water lake, and show that the lowering of its surface was not gradual and uniform, but that, after a relatively rapid lowering of the surface, the level of the water would remain stationary until a beach had been established. After the surface of the lake had been brought down below the level of the outlet, the position and course of which are still plainly discernible, the surplus water was disposed of by evaporation, in consequence of which the lake began to turn salt and, as the climate grew increasingly arid, the influx of water was diminished at the same time that evaporation was intensified. Consequently the lake shrank greatly in size and became more and more saline, until it was confined to the deepest part of the old basin. The site of Salt Lake City, which stands on a terrace well above the lake, from which it is eleven miles distant, was, at the time of the greatest expansion of the ancient lake, beneath 1,000 feet of water. The great plain which surrounds the modern lake is extraordinarily flat, due to the deposits of marl which were laid down on the floor of the ancient lake. The mountains of naked rock which rise from the plain and were islands in the ancient lake, show that these deposits rise to considerable heights above their bases. All the shore features of the old lake, the deltas made by inflowing streams, the beaches, bars, spits, and hooks are remarkably well preserved because of the slowness of denudation in that arid climate.

As saline lakes have no outlet, their size is determined by the balance between inflow and evaporation, and they are therefore subject to considerable fluctuation. A series of relatively cool, moist years, by increasing influx and diminishing evaporation, will cause the lake to rise and, conversely, a series of hot, dry years will lower its level. How far its surface area is affected by these fluctuations, will be determined by the shape of the basin. If the lake has low-lying and gently sloping shores, a small raising of the water level will greatly increase the area, while, if the shores are bold and steep, the enlargement of surface will be small. The fluctuations of the level are recorded by the beach lines; when the water rises, the former beach is covered from sight, but may be determined by soundings, which may reveal a whole series of such beaches below the existing surface. When the water level has been lowered, the old beaches are exposed to view. Raised beaches on the ocean coast imply earth movements, but beaches high above the present level of a lake require no such explanation.

The climatic changes which led to the formation of Salt Lake occurred in times which were long before the beginning of history, but the same principle applies to those lakes which have extensively fluctuated within the last few thousand years, the fluctuations of which record climatic changes. The general effect of these changes has been increased by desiccation in central and western Asia, eastern Africa, and western North America.

The deposits made by saline lakes in former ages of the earth's history are of great economic value at the present time. One such material which is thrown down from solution in brine is gypsum, from which plaster of Paris is made by heating the gypsum to a temperature which drives off the combined water. The immense bodies of rock salt which are found in so many parts of the world were all deposited from the evaporation of salt lakes. The salt desert of Lop-Nor in central Asia is the basin of a salt lake which has become dry within historic times, and left a mass of pure rock salt of undetermined thickness. In Germany (Stassfurt), in Alsace, and in Spain, potassium compounds are associated with the salt.

The ephemeral nature of lakes has been asserted in the preceding pages, and the proof of this may now be briefly stated. Lakes are obliterated by one or other of two processes, or by a combination of both, by filling up their basins with solid matter, or by the outlet's cutting down through the barrier which is holding back the water. For several reasons the filling process is much the more effective. The erosive power of running water is dependent upon the sand and stones which the river sets in motion, and the outlet of a lake is almost invariably clear and free from all sediment, which was thrown down in the lake. Lakes act as settling basins, and the motion of the water through them is so slow that it is practically equivalent to stagnation. In the Lake of Geneva, for instance, water is eleven years in passing from one end of the lake to the other. Such clear and sediment-free water, as the outlet of a lake almost always is, has but a minimum of erosive power. Again, the basins of many lakes descend below the level of the sea, and, save in closed desert basins, the outlet cannot excavate a channel below sea level; in such cases, therefore, the drainage can be only partial. Small lakes are frequently filled up by the growth of water plants, which extend out from the shore; generation after generation of these plants grow and die in the lake, and the partially decomposed vegetable matter accumulates until the lake is converted into a bog and eventually into dry land. Larger lakes are slowly filled by the sediments which are brought into them by various agents, of which the most effective are the inflowing streams. These build deltas of the coarser materials which the streams transport, and which are thrown down as soon as the stream's velocity is checked by the still water of the lake, while the finer particles are carried out and deposited in deeper water on the lake floor. If many streams flow into the lake, their juxtaposed deltas may form a fringe of deposits all around the shores. The position of the inflowing streams and that of shallows in the lake bed will determine the result of delta-building. A delta at one end of the lake gradually shortens it, as may be seen in the finger lakes of central New York. At the head of Seneca Lake is a delta which has filled in the lake basin and displaced the shore line for two miles or more northward. Deltas built from the sides may divide a lake into two or more parts. On the Tibetan plateau is a chain of five lakes, which lie at nearly the same altitude; the lowest, Lake Pangong, is salt, the others fresh, as they have outlets. "The five are really one, which has been divided into parts by the deposits of tributary streams. They occupy what appears to be part of an ancient winding river valley. The lakes and deltas together have a length of 105 miles, a maximum breadth of 4 miles, and an average breadth of only 2." (E. Huntington.) It is obvious that a continuation of these processes must eventually fill up the basin and obliterate the lakes. Subordinate processes assist in the work and shorten the time needed to accomplish it. Like the sea, large lakes cut back their shores, especially where the shore is formed by bold bluffs or cliffs. The sand and gravel thus produced and swept out into the lake contribute their share to the filling of the basin, as do also the dust and fine sand carried in by the wind. In many lakes, especially the smaller ones of fresh water, snails and mussels live in multitudes, and their dead shells accumulate in thick masses on the lake floor. Such animals do not live in swamps, and therefore when a bog or swamp rests upon a layer of shell marl, as is so frequently the case, we have the proof that the bog or swamp was formed by the partial filling of a lake. The number of filled lake basins which can be identified is very great; in Minnesota and in the Sierra Nevada Mountains, for example, thousands of such cases are known. The smooth, green meadow, through which meanders a stream, frequently retains the outline of a lake basin.

Economically, lakes are of varying importance. Large lakes may be busy highways of commerce, and one of the most frequented of such highways are the Great Lakes of North America, especially the four upper ones. A commerce of enormous volume and value has grown up, consisting chiefly of iron ore and grain coming down and coal going up. In the navigation season of eight or nine months, a large steamer passes Detroit, on the average, every twenty minutes, and the tonnage far exceeds that of the Suez Canal. The Caspian Sea, since the discovery of petroleum there, has become commercially important. Small lakes are frequently used as sources of water supply and ice, especially when it is practicable to protect their waters against pollution. Saline lakes are often utilized for the supply of the various substances which they contain in solution, such as salt, soda, potash, borax, etc.

PLAINS

By far the largest part of the earth's population lives upon plains, which are low-lying areas of little relief or topographical diversity; undulations, hills and valleys of gentle slopes and no very great height or depth, may cross a plain without changing its essential character. The distinction between plain and plateau, though of great importance, must be somewhat arbitrary. It is customary to take 200 meters (about 650 feet) as the dividing line between lowlands and highlands, but the Great Plains of the western United States are not so divided in ordinary usage. They rise by continuous and almost imperceptible gradations from the Mississippi River to the foot of the Rocky Mountains, where they have attained an elevation of 5,000 feet or more; but it is not customary to divide them into plain and plateau, though some geographers do make the division. No division yet suggested is satisfactory in all cases; the Piedmont Plateau is a lowland plain according to height, an upland plateau according to its boundaries.

Genetically considered, plains may be classified, first of all, into *constructional* and *destructional;* that is to say, the flatness of surface which characterizes plains may be due either to the deposition of material, on the one hand, or to its removal, on the other. Even in the latter case, destruction must, in most instances, have been preceded by construction, though that was in a long antecedent cycle of geographical development. Each of these two principal classes of plains has several subdivisions in accordance with the manner in which the construction or destruction has been effected and the principal dynamic agent.

Coastal plains have usually had a somewhat different history from plains in the interior of the continent. The Atlantic slope of North America has a coastal plain which, on the mainland, begins in New Jersey, with a breadth of 40 miles, and widens southwestward till it attains a width of 200 miles in Georgia. Including all Florida, it follows the Gulf of Mexico, sending a prolongation up the Mississippi Valley to the mouth of the Ohio, and extends through Texas into northeastern Mexico. This plain is everywhere an upheaved marginal sea bottom and is composed of a great thickness of almost undisturbed and slightly inclined beds of marine deposits, which for the most part are still unconsolidated and are strata of sands, gravels, clays, and the like, though in Florida and the Gulf States there are some consolidated limestones. Except for these limestones, the material is nearly all loose and friable, and there is very little rock in the ordinary sense of that word. The coastal plain, at its outer margin, is raised but very little above the level of the sea and rises very gently inland, till it meets the "fall line," where the harder and more ancient rocks come to the surface, forming the Piedmont Plateau. Could the submerged continental shelf, out to the 100-fathom line, be elevated into land, it would make the coastal plain about 100 miles wider than it is at present, but would not change its character. The plain is obviously constructional and owes its character to marine deposition and simple uplift.

The great interior valley, which stretches from the Appalachians to the Rocky Mountains, is an immense area, of which the different parts have had very different histories, but all agree in being built up of marine rocks, though the geological dates at which these rocks were deposited differ very widely. The States east of the Mississippi River, save for the coastal plain, and the greater part of those immediately west of the river, Arkansas, Missouri, Iowa, and Wisconsin, form a land surface of very high geological antiquity. The western portion of the Great Plains, neglecting, for the moment, the soft surface materials, is also a great area of marine rocks extending from the Gulf of Mexico to the Arctic Sea, but these are of far later geological date, though yet of great antiquity. Upon this foundation of ancient marine rocks, consolidated into hard strata of sandstone, limestone, shale and the like, is a rather thin and partial covering of much younger rocks which are far softer, imperfectly consolidated, and not of marine origin. These soft rocks were partly deposited in lakes, partly accumulated by the wind on land surfaces, chiefly, however, they are river-made deposits. Both coastal and interior plains are thus constructional in character, but very different in geological date.

The coastal plain of the Pacific side is a mere narrow strip between the Coast Range and the sea, which can hardly be said to exist in British Columbia or southern Alaska. In the Pacific region the lowlands are longitudinal valleys between parallel mountain ranges, like the valley of California. They are all constructional and chiefly marine.

Other types of constructional plains are those that are covered with glacial drift and those that are built up of volcanic substances. The desert basins of central Asia have been filled to an incredible depth with the débris of the encircling mountains, which has been brought in by the wash of streams and the transporting action of the wind, and thus deep, rocky basins have been converted into flat plains. The floors of ancient lakes, such as the plain of Salt Lake or that of Lake Agassiz, are extraordinarily flat and almost featureless, because of the thick mass of lake deposits which forms the surface. The pampas of Argentina are covered with a thick mantle of wind-accumulated dust, and their surface is so flat that the rain water lies long upon it without draining in any direction.

Destructional plains are likewise very common, these owing their flatness of surface and small altitude to the cutting down and removal of the rocks which once lay upon them. If sufficient time be given, there is no limit, save base level, to the amount of material which may thus be carried away. First, there is the plain of marine erosion in which the sea acts like a horizontal saw, almost everywhere cutting back its shores at a rate which depends upon local circumstances. Thus a wave-cut platform is made and is broadened seaward by the deposition of the material derived from the land, in which case the platform is described as "cut and built." This work is accomplished most rapidly and effectively upon a slowly subsiding coast, but subsidence does not appear to be a necessary condition. When reelevated into land, these platforms become plains of marine erosion, the breadth of which is determined by the length of time in which the work of the sea continued.

It is believed, though not by all geographers, that the subaërial agents are the most common and effective means of making destructional plains, and that the river and the atmosphere have done the greater part of such work. The geographical cycle, previously described, always ends, unless interrupted by crustal movements of the earth, in an approximate plain, be the rock structure what it may. The upland of southern New England, though usually classed with plateaus rather than with plains, has been reelevated and trenched by the river valleys of a new cycle, but its surface well illustrates a destructional plain as it was before the reelevation took place. The rocks are so folded as to indicate the former existence of mountains where now the surface has but small relief. There are vast areas in Canada of similar character.

Europe has a very diversified surface, but great plains occur there, especially in the east. A great plain borders the coast from the Pyrenees to the Urals, covering western and northern France, Belgium, Holland, north Germany, and Russia. Grassy plains extend from the north side of the Caspian uninterruptedly through Hungary to Austria and, by way of the Danube Valley, into south Germany. Russia is very largely a country of plains, the differences being chiefly in the character of the soil; northern Russia is covered with glacial drift, southern Russia with the famous "black earth," which is extremely favorable to the cultivation of wheat.

The vast and seemingly endless plains of Asia are, for the most part, arranged around the central mass on the periphery of the continent. Asia has a backbone of gigantic mountain ranges and table-land, both by far the highest in the world; central to the continent is an immense stretch of desert basins, some of which are below sea level, but mostly they are rather referable to plateaus. More than half of Siberia is covered by plains, but its southern and southeastern portion is made up of mountain and table-land. China is a country of plains, diversified by many mountain ranges, and the southern peninsulas, India and Arabia, have extensive plains. Africa is mostly made up of a high plateau, and consequently the proportion of plains of less than 600 feet in altitude is smaller than in any other continent. Australia also is mostly composed of a low plateau, ranging from 600 to 1,500 feet in height, and the proportionate amount of land between these levels is greater than in the other continents. There are very large low plains in the southeast, but the relative amount of land below 600 feet is small. South America has an immense low plain, less than 600 feet, beginning at the eastern foot of the Andes and covering two-fifths of the continent. The pampas of Argentina and most of Patagonia are true plains.

The reason why plains have most of mankind upon them is that agriculture thrives best upon these broad surfaces. The rich alluvial soils of river valleys support great populations, but such valleys are really narrow plains and belong in the same category from an economic point of view. For food and the raw materials of manufacture agriculture has always been the indispensable and fundamental industry, and as the mineral resources of the earth become more costly and difficult to obtain, the relative importance of agriculture seems destined to increase. Hence, fertility of soil, productiveness, and facility of transportation will long continue to make plains and lowland valleys the regions which can permanently support the largest population.

In the coastal plain of the United States the variety is almost entirely a matter of soil, belts of better and of inferior soil being encountered through the breadth of the plain and the length of Georgia and Alabama. The density of the negro population varies almost directly with the fertility of the soil, for the people of that race are prevailingly agricultural. It is on the low plains that cotton is grown. If, in addition, such a region has coal, metallic ores, and other raw materials, a very diversified industrial life will be developed, which may be almost self-contained and self-sufficing. Great cities will grow up as manufacturing centers at the points selected by the exigencies and facilities of transportation. The points where fuel and raw materials can be most easily assembled, and where manufactured goods can be best shipped in all directions, mark out the sites of the manufacturing and trading cities. It is this combination of agriculture, mining, and manufacturing which has brought such prosperity to the Middle West. At first, the rivers were the all-important avenues of transportation, and so the river towns, such as Pittsburgh, Cincinnati, Louisville, St. Louis, and New Orleans, throve mightily. When railways were introduced, the general flatness of the country and its gentle grades made construction easy. Towns already established became railroad centers. Chicago owes its growth chiefly to railways.

It is the lowlands of eastern China, plains in the north, table-lands in the south, that support such dense populations and where cultivation is so intensively carried on. The western half of the country is largely made up of highlands, and is far more sparsely peopled. Where water can be had, the plain is the principal seat of agriculture, and it is not necessary that there should be an abundant rainfall, provided rivers can supply the needed amount for irrigation. Egypt, which for thousands of years has maintained its productiveness, thanks to the annual Nile flood, has been more fortunate than Mesopotamia, now a parched desert.

CHAPTER IX

PLATEAUS AND MOUNTAINS

BETWEEN plains and low plateaus the distinction is seldom important from an economic point of view, but high plateaus differ very notably from low-lying plains, especially in the matter of climate, for altitude is as effective as latitude in determining climatic differences. Like plains, plateaus have been formed in various ways, constructional and destructional, but their height is, in almost all cases, due to elevation or upwarping. Some volcanic plateaus, however, would appear to have been built up to great heights by the mere piling of one lava flow on another. Others, again, have merely a cap of lava upon what would be a plateau without the volcanic materials. Many table-lands are composed of horizontal strata, which may pass into lower lands by a flexure or bend, or may be sharply demarcated from them by a great fault scarp. This is true of the great plateaus which lie to the west of the Rocky Mountains and culminate in the high plateaus of southern Utah and northern Arizona, through which the Colorado River has cut its great cañon. Over most of the surface of these vast table-lands the beds of rock are quite horizontal, though heights of 10,000 feet above the sea are found. Northward, the great plateaus gradually decline, until they merge in the Canadian plains. In Arizona much of the plateau is covered by a beautiful pine forest, for the support of which the winter snowfall suffices.

Mexico is very largely a plateau, which rises from a height of 3,000-3,500 feet at the northern border to 7,000 feet near the capital. The high plateau is between bounding mountain ranges on each side, and then drops rapidly to the sea; a belt thirty to forty miles wide on the east and west forms the hot lands (*tierras calientes*). The plateau, like those of the western United States, is composed chiefly of horizontal beds of rock of marine origin, which are crumpled and folded in the bordering mountain ranges. On the western side, the marine rocks are covered with great masses of lava flows and other volcanic material.

West of the Appalachian Mountains, in which the rocks are much folded, is the plateau, of no great height (2,000 to 2,400 feet), which has different names in different States; in Pennsylvania, it is the Pocono and Allegheny Plateaus, in Kentucky and Tennessee, the Cumberland Plateau. The strata are nearly horizontal, but inclined very gently westward, until they descend into the plains of the Middle West. Though a true plateau and composed of nearly horizontal strata, it is so like the mountains that it is frequently included and considered as a part of them. The plateaus of New England and of Quebec differ from all those that have been mentioned in being composed of very ancient and intensely folded rocks, which once were mountainous but have been worn down to base level and then reelevated. Much the same description would apply to the great plateau which takes in the greater part of Africa south of the Sahara, and its rocks are partly the intensely folded and metamorphosed rocks which have been planed down to an undulating surface, and partly very ancient sandstones and pudding stones which are more or less tilted.

The highest of all plateaus are found in Asia, the great table-land of Tibet attaining heights of 18,000 feet and having an average elevation of more than 16,500. The structure of the plateau is that of a mass of folded rocks, the valleys of which have been filled in by subsequent deposition, so that the surface is a constructional one, though other interpretations have been suggested. Asia Minor, particularly its northern part, Persia, Afghanistan, are plateaus of varying height. Asia also has by far the highest of existing mountain ranges, and its average elevation exceeds that of any other continent. Australia, nearly half of which is taken up by closed basins which have no outlet, is chiefly a low plateau; and South America has large plateaus to the east and north of the great central plain that lies at the eastern foot of the Andes. Finally, Antarctica is chiefly a high plateau.

It is generally the case that high plateaus have a more or less arid climate, principally because their situation is such that bordering mountains cut off the moisture-laden winds. Low plateaus, on the other hand, have much the same sort of climate as plains in a similar geographical situation would have. The extraordinarily lofty plateaus of Asia are, to a large extent, cold, stony, and uninhabitable deserts. Much of the great plateau of Africa is dry and some of it, the Kalahari, a desert. The high plateaus of southern Utah and northern Arizona have a semiarid climate. In Wyoming and Montana the plateaus are largely grasslands and form excellent ranges for cattle and sheep, which are very extensively bred in those States. In the north the Mexican plateau is very dry, but the rainfall increases southward. The temperature of plateaus, aside from their latitude, is determined by their height, the higher the colder. But ascent into the air is not quite the same thing as removal to a high latitude, for the light and direct heat of the sun are different in the two cases. Of course the length of the seasons and of day and night is not affected by altitude. Plateau climates, in cases where the table-land is not extremely high, are often very pleasant and healthful, while the lowlands in the same latitude are intolerable to white men. In Mexico three climatic belts are recognized; (1) the *tierras calientes,* or hot lands, which lie between sea level and an altitude of 3,000 feet and have a tropical climate; (2) the *tierras templadas* or temperate lands, which are between 3,000 and 6,000 feet in elevation and have a climate which is described as a perpetual spring; (3) the *tierras frias,* or cold lands, above 6,000 feet, in which the average temperature for the year is from 58 degrees to 62 degrees F.; the difference between day and night is often greater than that between summer and winter. In the mountains, of course, lower temperatures obtain. Europeans find that life on the Mexican plateau is entirely comfortable, but the low-lying, coastal lands are very unhealthy. Yellow fever, tropical malaria, and dysentery are rife, and white men find living conditions very difficult. Much the same difference is to be observed in tropical Africa. The lowlands of the western coast are proverbially dangerous to Europeans, and even Uganda on the plateau has been devastated by the sleeping sickness, which is due to the bite of a species of tsetse fly. Conditions on the east coast, in the region of Mombasa, are better, but by no means ideal. Farther south is the vast region called Rhodesia, which would seem to be very well suited for European colonization and has a very agreeable climate, although situated in the tropics. Still farther south, the Transvaal and the Orange River Colony are grasslands with a climate that is suitable for European settlement and, though not in the tropics, have very mild winters. In the extreme south, as on the east and west sides, the plateau breaks down to the sea in ways which differ in various places.

Whatever the structure of a plateau, it is attacked by the denuding agents and slowly removed. The rivers cut deep gorges which, at first, are separated by broad, flat-topped divides; but the valleys are widened at the expense of the divides until these become narrow crests, and when a plateau is cut up by numerous valleys, it is said to be "dissected." Unless counteracted by earth movements of uplift, the end must eventually be the complete removal of the plateau.

MOUNTAINS

The term "mountain" is very loosely used in ordinary speech, often meaning merely a mass that rises high above its surroundings; and what passes for a mountain in a low, flat country, would be but a hill in a truly mountainous region. In the Grand Cañon of the Colorado are pyramids of rock, carved by the eroding agents out of the cañon wall, which are higher than any mountain in New England and, if standing by themselves on a plain, would be very conspicuous and would surely be called mountains. In their present surroundings they are lost sight of, and it requires a strong effort of the imagination to appreciate their real size. Often fragments of plateaus, left standing after the removal of adjoining parts, are called mountains. Table Mountain, at the Cape of Good Hope, more than 3,000 feet high, is of this description and, rising as it does from sea level, is very imposing, especially when the "tablecloth" of cloud is in place. As its name suggests, Table Mountain has a broad, flat top and is composed of horizontal beds of sandstone. The Catskill Mountains, so called, which have summits surpassing 4,000 feet in height, are a deeply dissected part of the Appalachian plateau and have not the structure of a true mountain range.

Another category of mountains is that of volcanic cones, which are built up by the materials ejected from a volcanic vent. Mountains of this class may be placed anywhere on land or in the sea. A single cone may stand isolated on a plain, as do Vesuvius and Etna; or there may be a group of many cones, as in the Phlegræan Fields in Italy west of Naples. They may be built upon mountain ridges of another type, such as the magnificent cones of the Cascade Mountains, Mount Hood, Mount Rainier, and others, or the still loftier peaks of the Andes, Cotopaxi, Chimborazo, Aconcagua, etc. Many volcanic mountains rise from the bed of the sea, and the largest and highest existing volcanic cone is the stupendous mass of Mauna Loa in the Hawaiian Islands. The sea is there 15,000 feet deep, and the great mountain rises nearly 14,000 feet above sea level, where the diameter of the cone is 75 by 50 miles. Whether occurring in groups or lines, volcanoes do not form true mountain ranges, which are typically composed of belts of folded rocks, the length of which greatly exceeds the breadth. Volcanic débris may be piled up in an elongate and narrow belt to great thickness, and from such a mass erosion may subsequently carve lofty ridges and peaks. An example of this is the short range, called the Absaroka Mountains, on the eastern side of the Yellowstone Park, but the history of these mountains has not yet been made entirely clear. Block mountains, which are formed by the erosion of tilted blocks, inclosed between parallel lines of faulting, may simulate true mountain ranges in their proportions of length and breadth, but their structure is different.

Mountain ridges are grouped in series of ascending order of comprehensiveness. A *mountain range* is made up of a series of parallel ridges, separated by longitudinal valleys, which were formed at approximately the same geological date by the lateral compression of a continuous body of very thick sediments. This compression has crumpled the rocks into upward arches and downward bends, the latter forming the longitudinal valleys. A typical mountain range is very long in proportion to its width, and its ridges have a general trend in the same direction. This distinguishes true mountain ranges, formed by compression and folding, from the mountains which are carved out of a dissected table-land, however lofty it may be, for such ridges have no constancy of direction. This statement requires certain qualifications. The Appalachians are an excellent example of a typical mountain range.

Certain mountains of folding are exceptional in one or other particular. The Uinta Mountains of northern Utah, of which mention has already been made (p. 93), are formed by a single great upward arch of a thick mass of sediment, instead of by several parallel ridges and valleys; in other respects, they are a typical mountain range, whose serrate sky line and snow-covered peaks have nothing unusual about them. Another exceptional mountain group, it can hardly be called a range, is the Black Hills of South Dakota, which is a dome of crystalline schists from the higher parts of which the overarching strata have been removed by denudation. In ground plan the dome is oval, with no very great difference in length between the two diameters. Though called hills, Harney's Peak, their culminating point, is higher than any mountain east of the Mississippi River. In southern Utah is another remarkable group, the Henry Mountains, which have been formed by mushroom-shaped igneous intrusions that pushed the overlying strata into domelike elevations. These are all mountains of folding, yet only the Uintas could properly be called a range.

A *mountain system* is made up of a number of parallel or consecutive ranges, of approximately similar geological dates of upheaval, but formed by the compression of separate bodies of sediment. Thus, the Appalachian system comprises the Appalachian range, which runs from New York into Alabama, the Acadian range in Nova Scotia and New Brunswick, and the Ouachita range in Arkansas. These ranges are of approximately the same geological date of upheaval and have a common direction, from northeast to southwest, but they are not continuous, the sedimentary bodies of which they are composed being separate and distinct, and the Ouachita range is not consecutive with the others, but lies far to the west of them; nevertheless, that range is clearly a part of the Appalachian system, with which it corresponds in date.

A mountain range is a convenient subject of study because it has a certain unity of structure and origin. Almost all true ranges are made up of very thick masses of stratified rock, into which intrusions of igneous rock may or may not have been injected. The Appalachians, for instance, contain no igneous rocks, but the western ranges, such as the Rockies and the Sierra Nevada, have a core of intruded granite, from which the stratified rocks have been largely removed by erosion. The highest peaks have been carved out of the granite core, though that core was originally deeply buried under the overarching strata. A western range in which no igneous intrusions have been observed is the Uinta, and the deep river cañons which traverse these mountains afford exceptionally good facilities for examining their structure; everywhere they are formed by thick masses of strata.

When the folded rocks that make up a mountain range can be traced continuously into the unfolded strata of adjoining plains, it is found that the same beds are very much thicker in the mountains than in the plains. In the Appalachians the thickness of the component strata varies in different parts of the mountains, but is seldom less than 25,000 feet. Tracing these beds westward into the Mississippi Valley, they are found to become much thinner, not exceeding 4,000 feet. At the same time, there is a change in the character of the rocks; in the mountains, sandstones, conglomerates and shales predominate, which, west of the range, pass into limestones. This arrangement of marine sediments indicates that the thick masses which form the mountains were laid down along the beach and in shoal water, with subsiding bottom, while the limestones were formed in clearer and deeper seas to the westward and extending beyond the present line of the Mississippi River.

Such an immense thickness of strata is not at all peculiar to the Appalachians, but occurs in mountain ranges generally. In the Coast Range of California the beds are 30,000 feet thick, in the Alps 50,000 feet, and it is the general rule for true mountain ranges, throughout the world, that they are built up of enormously thick masses of stratified rocks. The thickness of strata is measured at right angles to their bedding planes and is what the strata would measure if they could be restored to their original horizontal position.

Another almost universal fact concerning the characteristics of true mountain ranges is the intense folding to which their component strata have been subjected. Frequently, too, they have been cut by gigantic faults. The degree of intensity of this folding varies greatly in different ranges, as does also the number of original ridges into which the beds were thrown by compression. An unusually simple case is the oft-mentioned Uinta Range of northern Utah. These mountains, which have an exceptional east-west course, are formed by a single huge and gently swelling arch, with a great fault along the northern slope. The curvature of the beds is so gradual that, in a restricted view, they often seem to be nearly horizontal. This may also be observed in certain parts of the Canadian Rockies.

Much more commonly the strata are thrown into many parallel folds, the upward arches forming the mountain ridges and the downward bends the intervening valleys, as is exemplified by the Jura Mountains of northern Switzerland.

The folds which make the ridges of the Jura are of no great height and are symmetrical, open, and gently undulating. But this gentle folding is not the rule among typical mountain ranges; intense compression is much more common; the Sierra Nevada Range is so intensely plicated, that the thickness of its component strata has not yet been ascertained. The Alps also show most violent contortion and even overturning of the folds, with immense faults and dislocations. The Appalachians are intermediate between these extremes, being less violently compressed than the Sierras or the Alps, much more so than the Jura, and the folds have been, as it were, pushed over away from the sea, so as to have a northwestward inclination, and there are also immense dislocations. Many, perhaps even most, ranges are bounded on one side by a fault; the Alps, the Sierra Nevada, the Wasatch and Uinta Ranges are familiar instances of this structure.

The two most characteristic and prevalent features of mountain ranges are, thus, the immense thickness of the strata which make them up, and the intense folding, fracturing, and dislocation to which the beds have been subjected and in consequence of which they are uplifted.

Masses of intrusive igneous rock, often on a gigantic scale, are very frequently associated with mountain ranges and form a large part of their mass. The great movements which resulted in the upheaval of the mountains at the same time forced the ascent of molten masses from the interior of the earth. These igneous rocks are not a necessary concomitant of true mountains; many ranges, such as the Uintas and the Appalachians, are without them, or have them in only insignificant amounts.

No human eye ever saw the birth of a mountain range, or has been able to detect its elevation in the act of moving upward. It is, therefore, possible only to infer the processes which have resulted in forming the mountains from the results as we see them to-day. Such inferences cannot always be drawn with convincing assurance, because of the difficulty of selecting the right one among several possible alternatives, and such difficulty leads to a difference of opinion and interpretation.

The first step in the formation of a typical mountain range is the building up of a great thickness of sediment, in an elongate, narrow trough, with slowly subsiding bottom. In most instances this trough was in shoal water closely following the shore of the sea, for the sediments of mountain rocks are almost always marine. The second step was the lateral compression of the thick mass of sediment by a force which acted horizontally and thus produced a series of parallel folds. Considerations of space forbid any discussion or even statement, of the evidence for this inferred lateral compression; that is one of the geological conclusions which we must take for granted. There is, however, a difference of opinion among geologists as to the immediate effect of the compressing force. The usual conception is that compression results, though with extreme slowness, in the formation of folds, which gradually rise above the surface of the ground and continue to rise, either without pause or intermittently, until the full altitude of the range is reached. According to this view, the most youthful mountain ranges, which have been least affected by denudation, would show the greatest difference of height between ridge and valley, or, in other terms, the maximum of relief.

A newer and alternative theory, which is favorably regarded by some authorities, is that folding is a deep-seated process which diminishes and dies away toward the surface, and that the first, or at least a very early, result of the compression is the elevation of a great block, like the Tian Shan, or the high plateau of Tibet, in which the rocks, though folded, form a surface with little relief, the folds being largely buried out of sight. According to this view the folds must first be brought to light by denudation, and the Jura Mountains are therefore far advanced in development, having had their folds exposed and partly cut away. This explanation would make it easier to account for the remarkable behavior of so many mountain streams, which cut through the ridges, one might almost say, by preference, instead of flowing around their ends, and thus passing from one longitudinal valley to another.

The time has not yet come to make a definite decision between these two conceptions of mountain formation which, it will be observed, do not differ radically, because too much remains to be learned of the subject. Nor is it necessary to suppose that all ranges were formed in precisely the same manner, differing only in the degree of violence with which the forces acted. Comparing a range made up of a single ridge, like the Uinta, with one composed of many parallel ridges, like most ranges, it is difficult to avoid the conclusion that a somewhat different process must have been at work in the two cases. The presence or absence of great intrusions of igneous masses is another difference which may perhaps indicate a divergence in the method of mountain formation.

Mountain ranges, as we now see them, even those of the latest geological date, have been very greatly modified by profound denudation, which has resulted in an enormous destruction and removal of their rocks. High mountains are regions of maximum rapidity of denudation, especially if they are so high as to rise above the limit of tree growth (usually called the "timber line" in this country) into the levels of perpetual snow and ice. At these heights the rocks are naked and unprotected by vegetation or soil. Frost, glaciers, torrents, and furious winds are unceasing in their attack, and the vast talus slopes of frost-riven rock fragments and the gigantic moraines are eloquent witnesses of the speed with which denudation is carried on. Even in naked desert ranges, the alternations of temperature and consequent expansion and contraction of the rocks result in enormous disintegration. In the Alps the complex folding and faulting, in conjunction with the vast denudation, have resulted in a chaos of forms so indescribably confused, that many problems of Alpine structure are still unsolved. Great valleys in the Himalayas have been filled to the brim with the débris of ancient glacial moraines, of such volume and on such a scale that descriptive terms fail even to suggest them. Landslips and rock-slides, caused by the action of ground water in reducing friction and facilitating gravity, sweep away whole peaks and ridges and carry them down to the lowlands. The torrents which flow down the sides of mountains are likewise effective agents of erosion and transportation because of the very high velocity of their currents. So rapid is the work of the removal of rock, that dwellers in high mountains are frequently made aware of important changes which have taken place in the familiar landscape within their memory.

The ruggedness and inaccessibility of lofty mountains and their lonely peaks, which make up so large a part both of the charm and the danger of mountain climbing, are due to this rapidity of denudation. Folding and faulting alone and unmodified would produce merely gently swelling curves, or bold lines of cliff escarpment along planes of dislocation. The central range of the Himalayas, as seen from Tibet, has a surprisingly even sky line, so little affected by denudation that it must be very youthful. The unnotched ridges of the Appalachians are also very characteristic, but are due to the complex history of those mountains.

The movements of compression and elevation, though very slow, are yet, in most instances, sufficient to generate a high degree of frictional heat, which, together with the intrusions of igneous rocks in a molten and intensely heated condition, produce extensive metamorphism in the rocks of many mountain ranges, though not of all. It is in the metamorphic rocks of mountains in very many parts of the world that are found the most valuable and productive ore bodies of such metals as gold, silver, and copper, and much of the iron. Aside from the heat of igneous intrusions, metamorphism is, in a general way, proportionate to the degree of compression which the rocks have undergone. The Sierra Nevada, the Blue Ridge, the central "massif" of the Alps, are all highly metamorphic, while the Jura, the Appalachians, and the Uintas show but little change of this sort.

Like lakes, mountains are comparatively ephemeral features of the earth's surface, always remembering that such a term has reference to the slow lapse and unimaginable length of geological time, not to the brief period which includes all human history. Within that historic period there have been but few topographical changes in the surface of the land, the time has been too short for that. The relatively short life of mountains is due to the especial rapidity with which denudation acts upon them, and the result of this is expressed in the fact that the ancient ranges are all low, while all the lofty mountains now in existence, in any part of the world, are of late geological date; and the result of the most recent studies of mountains has been to show that movements of upheaval have, in many instances, been continued, or repeated, until a much later time than had been previously supposed. Such mountains as the Rockies, the Andes, the Pyrenees, the Alps, the Caucasus, the Himalayas, all originated in the later periods of the earth's history, and the St. Elias Range in Alaska would seem to be the youngest of all the great ranges.

Conversely, very ancient mountains are low, whatever they may once have been. The Appalachians, the Laurentian Highlands of Canada, the Taconic Range of western New England, the Armorican Range in Brittany, and the mountains of central and southern Germany, are examples of very ancient mountain ranges that have been worn down to mere stumps. The Appalachians may once have rivaled the Rockies in height, though there is no present means of determining what their maximum height actually was. However that may have been, these mountains have at least twice been worn down to an approximate plain, raised but little above sea level, and with high points left standing on their surface only here and there, as monuments of the former high level. Of these monuments, the mountains of western North Carolina are the most conspicuous. The reelevation of the approximate plain into a dome of very gentle slope and no great height was followed by the carving out of longitudinal valleys along the soft rocks, leaving the harder rocks to stand up in relief as the existing ridges. In the Appalachians of to-day the ridges are everywhere composed of the more resistant rocks, which is sufficient evidence that the modern relief is due to denudation rather than to folding. It is this carving of a slightly upwarped plain into ridge and valley which has given their very exceptional form to the Appalachian ridges, with their long, even, and level sky line, lacking the serrations and peaks so characteristic of most of the existing mountain ranges.

The low plateaus of southern New England and Quebec are reelevated plains, and are composed of such intensely folded rocks as to indicate that they are the sites of ancient mountain ranges which have been completely worn away down to their very roots. When these plateaus shall have been maturely dissected, other forms of upland will be brought about and some semblance of mountains may be restored, but, if so, they will be the product of a selective denudation.

A volume might be written concerning the influence of mountains upon human interests, civil, economic, and military, so varied and far-reaching has that influence been. Like other geographical factors, the influence and importance of mountains and of particular ranges have changed from time to time in accordance with the advance of civilization, but they are never negligible and are often supremely important.

From the economic point of view, mountainous regions are so generally the scene of mines, that the German words for mine (Bergwerk) and mining (Bergbau) involve the term mountain (Berg). Coal has no necessary association with mountains and, when found in them, like the anthracite of Pennsylvania and the soft coal of the great Appalachian field, the connection is accidental and merely means that coal-bearing strata happened to be involved in the operation of folding. Coal may occur in any sort of topography, in mountain, plain, or plateau. The importance of mountain regions as mining lands, as pointed out above, is for metallic ores; and the more igneous bodies and metamorphic rock that a given range contains, the more likely it is to be rich in valuable minerals. As has been repeatedly mentioned, the Appalachians have little igneous or metamorphic rock and, aside from iron, correspondingly little metallic wealth. In the mountains of the great cordillera of the Pacific, the ranges, for the most part, have great masses of igneous and metamorphic rocks and their mineral wealth is proverbial. From Alaska to southern Mexico are long series of rich mines of gold, silver, copper, and lead, and the Andes continue the "mineralized" belt far into southern Chile. It was the gold and silver of the South American mountains which led to the Spanish conquest, and the copper mines of the Andes are still of great importance. To the Roman Empire, the mountains of Spain and Greece were the sources of supply of metals, and in the production of copper, lead, and mercury Spain is still the leading European country.

In addition to these metallic ores which have been known and valued almost since the beginning of civilization, modern methods of steel making have given great importance to certain rare metals which, until quite lately, were little used. Tungsten, nickel, chromium, vanadium, molybdenum, and the like are now employed to make steel alloys for certain particular purposes, for greater hardness, toughness, tensile strength, etc. The motor-car industry may fairly be said to be dependent upon these alloys, which permit a great diminution of weight without undue loss of strength. Except nickel, most of which comes from Sudbury in the Province of Ontario, these rare metals are chiefly the product of the western mountains.

Another economic use of mountains, which may be of the greatest importance, is for the growth of forests. Steep and high mountains are not favorable to agriculture which, under such conditions, is practicable only when the population is dense and labor cheap, for such cultivation is extremely toilsome. Forests can be advantageously established and, under a scientific system of forestry, can be made profitable on mountain land which is fit for little else; and there is the further advantage that, in this manner, the soil is protected against removal by rain wash and is steadily enriched, while the springs and streams are maintained. The European governments, especially Germany and what once was Austria, have planted great forests on all the low and medium-height ranges of the country. The Harz, the Taunus, the Thuringian Forest, the Black Forest, are familiar names of the forested mountains in Germany. The French Government has spent great sums in reestablishing the forests which were destroyed in the first revolution, and with results which proved of inestimable value in the late war. At a time when ship tonnage was so precious and so hard to get, the French forests were able to supply the American army with timber, when it was impracticable to bring that timber across the Atlantic and equally impracticable to dispense with it. The forest reserves which the United States Government has established in many parts of our country are, for the most part, mountain forests, and their maintenance is important for the conservation of the water resources in regions which are arid or desert save on the mountains.

In addition to their importance as mining and forest regions, mountains have played a great part in the history of mankind. High mountains are the most effective barriers to the movements of bodies of men, whether organized or in mere hordes, far more so than rivers or ordinary lakes, which can be readily crossed, even though the art of navigation has not yet developed beyond the making of rafts. The Pyrenees are a remarkably perfect barrier, and for many centuries they have separated the two very different civilizations of France and Spain. The mountains, though not so high as the Alps, form a more unbroken mass; at only two points are they crossed by railroads, and at only three by roads. The boast of Louis XIV, when his grandson Philip was raised to the Spanish throne, that the Pyrenees no longer existed, was mere rhetoric. The accession of a French king, despite "Family Compacts" and Bourbon alliances, did nothing to fuse the two peoples. To this day Spain is one of the most isolated of European countries.

The Alps were the great obstacle to the spread of Roman commerce and Roman dominion over western Europe, and until their passes had been secured, the conquest of Gaul and southern Germany was uncertain. Before the Roman conquest and in the Middle Ages, the Alpine passes enabled the people in possession of them to exact toll or blackmail from the traffic passing through. Both north and south of the mountains, the situation of towns with reference to the passes was often the chief factor in determining their prosperity and growth. Turin is an instance of this; the mountains describe a great arc of a circle, concave to the south, and lines drawn through the principal passes converge to a point, near which is Turin, a circumstance once most favorable to that city, though no longer of such great significance. In the Middle Ages Augsburg and other south German towns owed much of their commercial importance to the Italian traffic which came to them through the passes in the Alps.

As civilization progressed and peaceful conditions became more and more normal, the great passes became more important, rather than less, because they determined the locations of the great mountain roads and afterward of the railways. The great railway routes between Italy, on the one hand, and France, Switzerland, Germany, and Austria, on the other, followed these passes. Owing to the steepness of the grades, it was necessary to bore very long tunnels through the mountains, the Mont Cenis, the Saint Gothard and the Simplon, the longest of existing tunnels. The Brenner Pass, which leads from Verona into the Tyrol and Bavaria and is now the line of a railway, is the lowest of the Alpine passes, less than 4,500 feet above sea level. This pass was the principal gateway from the north into Italy and was made use of in the Teutonic invasions, and was throughout the Middle Ages the great highway of commerce and travel, and was the first of the passes in which a carriage road was built (1772). Napoleon's great military road over the Simplon Pass was not completed until 1807, and roads over the other passes were still later. Though four lines of railroad now cross the Alps, those mountains continue to take a large toll from commerce, much as the holders of the passes did in mediæval times. Because of the high temperatures that are encountered within the mountain masses, it has been necessary to place the tunnels far above sea level; the lowest of them is the Simplon tunnel, at an altitude of 2,313 feet. These steep grades and the interest on the immense sums put into the construction of the tunnels make up a tax upon every train that passes, the toll exacted by the mountains.

The Alps of to-day represent the highest form of mountain civilization that has yet been reached. In Switzerland the lowland cantons are densely populated, have very extensive industrial interests, and carry on a very large commerce, both export and import. Only a relatively small part of the country can be cultivated, so very large a part of its surface being composed of naked rock and fields of ice and snow. Above the line of villages which are tenable in winter, and where the snowfall is not so very heavy as to prevent the people from getting about, the mountains have a small, temporary population which is engaged in caring for great herds of cattle, which are driven to the high-level pastures, above the forest zone, for the summer season. These same people make very large quantities of butter and cheese, which are important articles of commerce in Switzerland and especially of the export trade. With the approach of winter, the cattle are driven down into the lowlands and, of course, the number which can be carried through the winter will determine the number that can be sent to the mountain pastures in summer.

Another way in which Switzerland is taking advantage of her high mountains and abundant precipitation is in the development of hydroelectric power, to which the results of ice action in the Glacial Epoch were particularly favorable. Water power is already an immensely important feature of mountainous countries and is almost certainly destined to become more so with the passage of time.

To attempt even the barest outline of the influence which mountains have exerted upon history, would be to rewrite almost all history. Attention is directed to the rôle played by the Appalachian Mountains in the early history of the American colonies and, seeing how low and relatively insignificant these mountains are, it appears very surprising that, until nearly the end of the eighteenth century, they completely hemmed in the British settlements along the Atlantic seaboard. There were, however, other factors that added to their effectiveness as barriers. Including the plateaus, there was a broad belt of rough, broken, densely forested country to cross before the westward flowing streams were encountered, and the chain of posts which the French had established made them the masters of the country. Even after the conquest of Canada had established British supremacy east of the Mississippi, speedily followed by the successful revolt of the thirteen colonies, the hostility of the forest Indians greatly retarded the westward movement of emigration. The "dark and bloody ground" of Kentucky was eloquent of the price that had to be paid for the new lands of the West. The tide of emigration left stranded, as it were, a population of settlers in the mountains, who had no slaves and were always hostile to slavery, so that, when the Civil War broke out, the mountaineers remained devoted to the Union and greatly added to the difficulties of the Confederacy, into whose territory the mountains made a deep incursion. Even to the present time, south of Pennsylvania, the mountain barrier remains as a formidable obstacle to east and west transportation, and is crossed at only a few points by lines of railway.

In 1389 the disastrous battle of Kossovo overthrew the Serbian empire and established the dominion of the Turks, but the Serbs who took refuge in the chaotic mountain mass of Montenegro have maintained their independence for more than 500 years against all that the Turks could do to bring these brave mountaineers under the yoke. In this respect history has often repeated itself, for many times have mountains proved the refuge of conquered and persecuted peoples and enabled them to maintain their independence. The British tribes who would not yield to the power of Rome found shelter in the mountains of Wales, which has preserved their language to this day. The Highlands of Scotland were not conquered till after the insurrection of 1745, and the Alps enabled the Swiss to assert and maintain their independence against Austria. In the late war, there is much reason to believe, it was the excellent Swiss army and its strong position in the mountains which preserved Switzerland from the fate of Belgium, for both countries offered an easy path to the unfortified portions of the French frontier; but the Swiss adventure was much more hazardous than the Belgian, and had the further disadvantage of bringing the invader into a part of France very far removed from Paris.

Napoleon's campaigns in northern Italy in 1796 and 1797, and especially in 1800, made a marvelous use of mountain topography, and the famous crossing of the Alps to the Austrian rear in 1800 led to the great victory of Marengo and the definitive conquest of the peninsula, which remained in the hands of France until the overthrow of the Emperor in 1814.

Italy entered the World War in 1915, in the well-founded hope that she might rescue from Austrian rule the large Italian-speaking population of "Italia Irredenta," the Trentino and Trieste. Many anxious friends of Italy were surprised and grieved by the slow progress made by the Italian armies, but this surprise was due to a lack of information concerning the topographical conditions against which the Italians had to contend and which were all in Austria's favor, overwhelmingly so, in fact. The Austro-Italian frontier, as it was before the war, ran along the southern foot of the Alps, near the piedmont plain of northern Italy and, in that region of the Alps, the topography is excessively rugged, affording to the Austrians one line after another of almost impregnable strength, and affording the most perfect points for the observation of hostile movements. Eastward, the plain abuts against the mountain ridges which curve southward from the main mass of the Alps to follow the Dalmatian coast, and the deep gorge of the Isonzo, just east of the boundary, afforded a defensive position of great strength. Not only was the topography all in favor of the Austrians, but the Austrian province of the Trentino made a dangerous salient into the Italian line, commanding the passes and exits from the mountains.

Throughout the history of mankind, mountain ranges have thus played a very important rôle, whether as barriers, places of refuge, or as the determining factors in military operations; but they are always regions of scanty populations, even relatively low mountains, for they are not favorable to agriculture. Areas of mining may be densely peopled, but they are small in comparison with the whole mountain region.

The special virtues of mountaineers, their bold hardihood, their self-reliance, and indomitable love of freedom, have been the theme of many panegyrics. Speaking of the Ladakhis of central Asia, Huntington says: "Perhaps the most noteworthy fact with regard to the people is that their characteristic traits of comparative honesty, courage in spite of superstition, industry, intense love of home, and cheerfulness under difficulty, are those which, all over the world, seem to make mountaineers, of whatever race, better men than the inhabitants of plains, where life is easy."

From the standpoint of present knowledge, it seems to be an assured fact that the economic importance of mountains, and especially of those which are well watered, is bound to increase in the future.

CHAPTER X

SEACOASTS AND ISLANDS

THE seacoast is not merely a line, as it appears on an ordinary map, but a zone of varying breadth on the margin of the land, which slopes toward the sea and has a subaërial and a submarine portion. The submarine extension generally continues the slope of the land portion, with a more or less pronounced interruption at the beach, where the surf breaks. On flat, low-lying, and gently sloping coasts, the beach is generally wide, especially if the rise and fall of the tide are large. A beach wall, or low ridge of pebbles and sand, piled up by the action of storm waves and above the reach of the ordinary surf of average weather, is generally present, and is most conspicuous when made of cobblestones, or "shingle," though it is not lacking on beaches that have no shingle or gravel, but are altogether composed of sand. Behind the beach wall there may be a belt of sand dunes, formed by the action of the wind and varying in breadth from a few yards to many miles. On steep and rocky coasts the beach is usually narrow, and if fairly deep water continues to the foot of the cliffs, there may be no beach at all. Such features are generally determined by earth movements.

Among the coasts of the various continents there is very great variety, and in a short journey one may encounter many different kinds of coast. On the eastern side of the United States, for instance, we find in the coast of Maine, that of Massachusetts, and that of New Jersey, three very different types of shore, though it would be a superfluous subtlety to follow the lead of a German writer who distinguishes thirteen separate varieties of coast between Chesapeake Bay and the Maine border. Coasts which are near together may be, and frequently are, of totally different character, and in the strongest possible contrast. Take, for example, the coasts of Norway, Sweden, and Finland, bold, rocky headlands, countless deep fiords running far inland, and a labyrinth of islands and deep channels off the shore. The Baltic provinces of Russia, and the German coasts on the Baltic and North Seas, are low, flat, and featureless, with few islands or indentations of the shore line, save where rivers enter the sea. Belgium and Holland are proverbially the "Low Countries," so little raised above the sea that much of the surface, especially in Holland, is kept dry by an elaborate system of dikes.

In view of this great variety of form and character among the various kinds of coasts, some sort of a classification of coasts is indispensable, and many such schemes have been proposed, the best known of which are the classifications of Von Richthofen, Penck, Supan, and Suess, and the latter is the one which is, perhaps, most widely used among English-speaking geographers. According to this scheme, two principal kinds of coasts are recognized which, because of their prevalence on the shores of the oceans named, are called respectively the Pacific and the Atlantic types of coast. Gregory has modified the scheme by recognizing two subdivisions of the Pacific type. The Pacific type is best exemplified by the western shore of the Americas, which is also the *concordant* type of Supan; everywhere, from Alaska to Cape Horn, high mountain ranges determine the coast line, with all its curves and projections, the coast being parallel with the mountains. On the Asiatic side, a somewhat similar arrangement is to be observed, but with the important difference that here an inner and an outer coast line must be distinguished. The outer line is that of the islands, from the Aleutians to New Zealand, and this line is concordant, determined by the mountain ranges, as on the American side, but the inner line, that of the mainland of Asia, is different. Part of it belongs in the *neutral* division of Supan; that is to say, it is made up of horizontal strata or of unstratified rocks, and such rocks have no one line of prolongation on the surface, as inclined or folded strata do have. Being, therefore, neither concordant nor discordant, the coast is said to be neutral. On the mainland of Asia, the low-lying plain of China comes down to the sea level by a series of gigantic steps, made by tilted fault blocks. South of the great plain, mountains appear again, but now they do not run parallel to the coast, but intersect it at acute angles. The sea thus cuts alternately into the upward and downward arches of the folded beds, that is, into the ridges and valleys.

Gregory thus defines the two coastal types which border the Pacific: "*Primary Pacific Coasts* are determined by the proximity of long lines of fold mountains, to the trend of which the coast is in general parallel. The mountains bounding these coasts are of comparatively young geological age. Overthrusts and overfolds, if present, are mostly diverted toward the ocean. *Secondary Pacific*, or

Sub-Pacific Coasts are due to the subsidence of basins on the inner side of mountain chains along coasts of the Primary Pacific type."

The Atlantic type of coast is *discordant* (in Supan's term) and is well exemplified by the west coast of Europe, where the mountain ranges have a course approximately at right angles to the coast line; in the southwest of Ireland the sea has filled long valleys cut into the land along the line of the softer rocks, which trend away from the coast. While the coasts of Europe are generally discordant, there are some exceptions; the Scandinavian peninsula and the north coast of Spain are concordant, and most geographers would put the Mediterranean shores of Europe, Africa, and the West Indian Islands into the concordant or Pacific class.

A great and significant characteristic of the two types of coast mentioned, the concordant and the discordant, is that the concordant type shuts off the interior from the sea, save by occasional passes through the mountain wall, though passes are not invariably present. On the other hand, the discordant coast opens up the interior to invasion from the sea or, equally well, permits movement in the opposite direction, from the interior to the coast.

On the Atlantic side, where the mountains trend obliquely away from the sea, the English settlers found the broad and generally fertile coastal plain awaiting them. It is true that the Appalachian wilderness acted as a barrier, holding back the colonists until after the middle of the eighteenth century, but the barrier was a temporary one and acted to the advantage of the British, whose great strength in North America, as compared with the weakness of the French, lay in the relative compactness of their settlements and the much larger population which grew up in those settlements. Owing to the discovery and colonization of North America from the discordant Atlantic coast, the opening up and settlement of the new continent took place with comparative ease and rapidity. Had the attempt been made from the Pacific side, the concordant coast line and parallel mountain ranges would have delayed the settlement in a manner not easy to calculate.

In South America the difference between the two sides is even more striking, because the Andes are a very lofty range, with few passes, and exceedingly difficult to cross, while the narrow coastal strip, from Ecuador to southern Chile, is a rainless desert. On the Atlantic side the coast is low, and there are no long ranges of mountains to bar the way into the interior. Led on by the lure of gold, the Spaniards very early made the conquest of Peru, but they did not use that conquest as a base for the invasion of Argentina. It is true that to this day there are large parts of the interior of Brazil which are still unknown, but there the barrier is the tropical climate and the jungle, that, so far, invincible foe of the white man's civilization. That the Americas are open on the Atlantic and nearly closed on the Pacific side, has made the New World a part of European, rather than of Asiatic, civilization.

Another scheme of coastal classification is the division into *regular* and *irregular* coast lines. Regular coasts have no considerable indentations, but are made up, for the most part, of a series of gentle curves, convex toward the land and concave toward the sea. The lower and flatter the coast, the more perfectly is this type of regularity displayed, as in the shores of Florida and Texas. If the slope of the land toward the sea is steep while the general direction of the coast is regular, a map of it makes the coast line look as though drawn by a trembling hand, with numerous little projections, not more than a few hundred yards in length and separated by shallow indentations. Low-lying, flat coasts generally border coastal plains and are usually regular, while regular, steep coasts are bounded by lines of cliff, which abruptly limit the slope of the land toward the sea, and the cliffs, though pursuing a uniform direction, are broken by small bays. Such a coast, like the west shore of Ireland, for instance, shows advantageously the destructive work of the waves; sea caves, natural arches, isolated pillars, stacks and pyramids, and, running far out to sea, lines of rocky shoal and ledge, over which the sea boils in fury, are the usual accompaniments of such coasts. The submarine part of the slope on this kind of regular coast is usually more gentle than the slope of the land, and descends gradually to depths of ten or twenty fathoms. Above water, the height of the sea cliff is seldom more than 300 or 400 feet, and consequently this variety of regular coast is best seen in lands which are rather low. Mountainous coasts, such as that of southeastern China, give rise to different topographical forms.

Regular coasts are fringed by few islands, or, it may be, by none at all. The east and west sides of South America and of Africa are familiar instances, except that in the far south the regular west coast of South America becomes highly irregular and has great numbers of islands fringing the shore. Aside from Madagascar, the oceanic coasts of Africa are practically without islands, for the volcanic islands in the Atlantic, such as the Canaries and the Cape Verde group, have no particular relation to the African continent.

Irregular coasts are very varied in form, because of their diversity in mode of origin, but they all agree in having numerous bays, which penetrate far into the land, sometimes narrowing regularly inland, sometimes of variable width, expanding into a lake, or narrowing to a strait, but always ending in a land valley. Irregular coasts have many islands, which are frequently in line with the headlands between the bays. The land back of an irregular coast may be low or high, steep or gently sloping, and the land slope continues beneath the water, until it joins the flat sea floor. The two shores of the Adriatic Sea afford excellent and strongly contrasting examples of the regular and irregular types of coast. On the Italian side the coast line is regular, nearly straight, and almost altogether without indentations or harbors. Not only is the coast straight, regular, and devoid of indentations, but it is low-lying and flat and, for its entire length from Venice to Brindisi, it lies open to bombardment from a hostile fleet. The eastern shore, or Dalmatian coast, on the other hand, is highly irregular; it is a bold, rocky coast, with innumerable indentations, many excellent harbors, and very numerous islands, and this irregularity of shore line continues for the whole length of the Balkan Peninsula to the southern end of Greece. This Dalmatian, Albanian, and Greek coast (for the three are continuous) is quite impregnable to naval attack and furnishes many advantageous points from which a naval offensive can be started. The Italian navy in the Adriatic labored under almost as great a disadvantage in having the Dalmatian coast, with the harbors of Trieste, Fiume, and Pola, in the hands of the enemy, as did the Italian army in trying to break through the impregnable wall of the Alps. Austria's friends, and even her foes, had made sure that Italy should be rendered helpless against her, either offensively or defensively; and had the war been between those two powers only, and had Austria been free to put forth her whole strength against Italy, it is difficult to see how Italy could possibly have overcome the immense topographical advantages which Austria possessed for both military and naval operations.

All of the preceding schemes of coast classification are purely descriptive and tell very little concerning the manner in which the various types of coast have been produced. To be satisfactory, a classification should be genetic, the principle which has been made use of in classifying the geographical features dealt with in preceding chapters. Professor D. W. Johnson has proposed such a genetic scheme for the subdivision of coasts or shore lines. (1) *Coasts of submergence,* produced by a depression of the land and invasion by the sea, which fills the lower valleys. (2) Coasts of *emergence,* made by an elevation of the sea bottom, which is added to the land, causing the sea to withdraw correspondingly; the new shore line is determined by the amount of upheaval and the slope of the sea bottom. A coast of submergence is one the principal features of which are due to depression of the land, though depression may have been followed by a slight re-elevation. Similarly, a coast of emergence has its character determined by an elevation of the land, even though that elevation should have been followed by a downward movement of much smaller amount. (3) *Neutral coasts* are those whose essential features are not determined by either submergence or emergence. It should be noted that this use of the term *neutral* differs altogether from the meaning attached to the word by Supan (see p. 248) who employs it for coasts which are made up of horizontal strata or of unstratified rocks. In this case the neutrality is between concordant and discordant shore lines. (4) *Compound coasts* are those whose characteristics combine those of two or more of the preceding classes, so that they can hardly be referred to one rather than to the other.

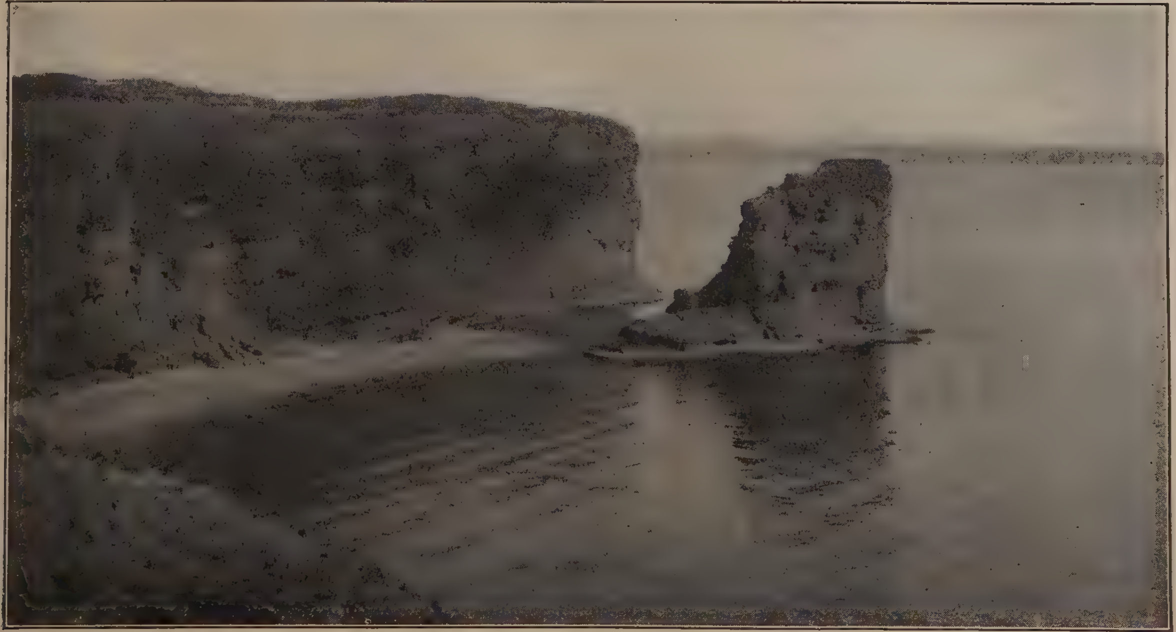
Just as we have found to be the case with other geographical features, sea coasts pass through a cycle of development, in which the stages of youth, maturity, and old age may be distinguished, but these stages are quite independent of the cycle through which the adjoining lands, mountains, rivers, etc., may be passing. The base level of wave erosion is the depth below tide to which the waves can cut down, and is not determined or affected by the base level of denudation by the atmosphere and by rivers. After a land region has been base leveled and is losing almost nothing more by stream action, the waves of the sea will continue to cut back the shore line. If there is no earth movement of elevation or depression, there is no known limit to the cutting action of the sea, though as the submarine platform, covered with shoal water, is broadened, the cutting action is retarded. The land cycle, in regions other than closed desert basins, is from low-lying, featureless plain back to another plain of the same character, but the coastal cycle is from shoal water back to shoal water, and could the ideal cycle be simultaneously completed for all coasts, all the land would be swept away and the earth be covered by a universal sea. There is no reason to think that this has ever happened.

Another way in which the independence of inland and coastal cycles appears, is to assume the extensive submergence of a land surface, with a maturely developed topography showing the maximum relief; the result would be a combination of youthful coast line with mature inland country. Then, too, there is no necessary relation between subaërial and marine denudation; the former ceases when the land is base-leveled, the latter continues so long as any land is left above water.

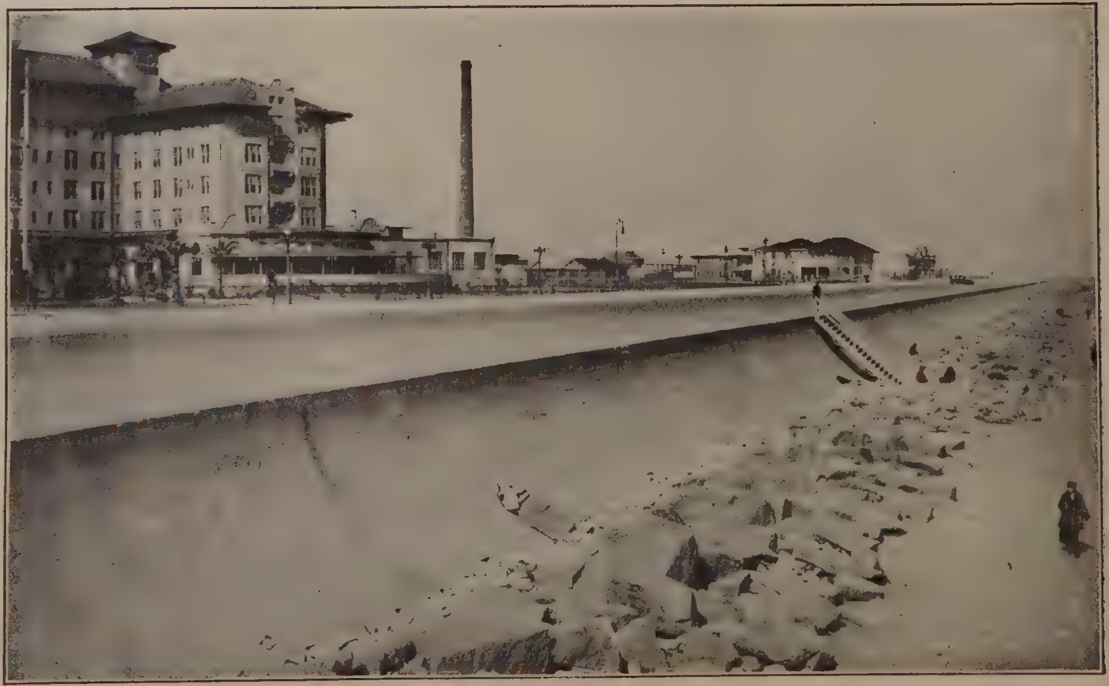
1. *Coasts of Submergence.*—Irregular coasts are always coasts of submergence; they represent a land surface of more or less maturely developed topography which has been invaded by the sea, and the character of the shore line is determined by the antecedent nature of the land surface which is now submerged. The greater the relief of that surface, the more diversified it is with ridge and valley, hill and dale, the greater will be the resulting irregularity of the coast. The lower valleys are "drowned," which means that they are invaded by the sea, and the rivers which occupied them are converted, for more or less of their length, into tidal estuaries. The Hudson Valley is a familiar instance of a drowned valley; its submarine channel has been traced across the sea floor far to the southeast of Sandy Hook; New York Bay is a portion of the valley which has become wholly marine, and above the bay to a point a few miles below Albany, where is the real mouth of the river, the valley is filled by a tidal estuary. Chesapeake Bay is the drowned

and sea-filled lower valley of the Susquehanna, which once received as branches all the streams, such as the Potomac, the James, and many others, which now empty separately into the bay. Isolated high points on a coast of submergence are converted into islands, and high ridges become the headlands and promontories, which jut out boldly into the sea and separate the drowned valleys, now bays and estuaries, from one another.

It is evident that the character of the coast of submergence is determined by the antecedent character of the land before submergence. A low, flat, and featureless plain will, when partially submerged, give a perfectly regular and nearly straight coast line, in which the only indentations are formed by the mouths of rivers. Were the coastal plain of the Atlantic States to be depressed and, to a larger or smaller extent, covered by the sea, the resulting shore line would be very like the present one, though the sand spits and offshore bars would be absent and the shallow bays, like those which fringe the south shore of Long Island and Barnegat Bay in New Jersey, which are inclosed by the spits and bars, would also be lacking. A landscape which is diversified and has a strong relief, with high ridges and deep valleys, isolated hills or mountains, will, on submergence, give rise to a coast like that of Maine, extremely irregular, with bold headlands and deep indentations and numerous islands forming an outer fringe. The coast of New Jersey and the coast of Maine are both shores of submergence, and the very striking difference between them is due to the different character of the land areas submerged, and subdivisions of the submerged coasts are made in accordance with the character



COAST OF NEWFOUNDLAND, WITH A "STACK," SHOWING THE RETREAT OF THE CLIFFS BEFORE THE ASSAULT OF THE WAVES



THE GALVESTON SEA WALL. This was constructed to protect the city against such an inundation as occurred during a hurricane in 1900. The grade of the city was raised as a further protection of the land surface as it was before submergence took place.

1. *Ria Coasts,* named from the "rias" of northwestern Spain, are produced by the drowning of ordinary river valleys which have been excavated in plains, plateaus, or mountains. The Chesapeake Bay shore is a ria coast in a plain, while the coast of Maine or of northwestern France, or Spain, is a ria coast produced by the submergence of a mountainous region. The Dalmatian coast on the eastern side of the Adriatic Sea, is also a ria shore among mountains of folding. The bays of ria coasts are shorter, more funnel-shaped, and much shallower than fiords, gradually and regularly broadening and deepening seaward. The valleys which have been submerged and invaded by the sea have not been glaciated, and ria coasts are therefore found abundantly in temperate and tropical latitudes, in Ireland, Brazil, China, Australia, in addition to the coasts enumerated above. They occur most commonly on the margins of lands of moderate height, but may be found in areas of any elevation, high or low. They are not associated with any particular type of rock or of geological structure. In Spain and in Brittany, for example, the rock is granite, but in other cases, as in the southwest of Ireland, the bays occupy longitudinal valleys cut out along the softer sandstones, while the intervening ridges are formed by the more resistant limestones.

Rias may be formed in valleys of folding, as in the previously mentioned Dalmatian coast, and an unusual form is exemplified by San Francisco Bay.

This bay is T-shaped and follows a longitudinal valley which is parallel with the coast and which runs northward and southward above sea level into the great valley of California. The transverse connection with the Pacific through the Golden Gate is, like the bay itself, a drowned river valley, and soundings show the existence of an ancient delta on the sea floor outside of the Golden Gate.

2. *Fiord* (or *Fjord*) *Coasts* have long been a bone of contention among geographers. Most of the American writers are satisfied that fiords are of glacial origin, but some American and many European geographers attribute them to other agencies. Fiord coasts occur in the high latitudes of both hemispheres and in regions which have been subjected to glaciation. In the northern hemisphere their limit equatorward is the 49th parallel of latitude, and in the southern hemisphere the 41st parallel. It is also noted that fiord coasts occur almost always on the western side of land areas. Alaska, British Columbia, Greenland, Scotland, Norway, southern Chile, and New Zealand have typical fiord coasts. Fiords are inlets from the sea, long, narrow, branching, and usually very deep, but not, as a rule, with the bottom having a uniform seaward slope. The bottom, in most instances, is made up of one rock basin, or of several such basins in a line, and is usually deeper in the middle of its course than at its seaward end and sometimes it is continued across the sea floor as a submarine valley. The ridges which separate fiords are frequently notched by low passes, which seaward become straits, cutting up the headlands and ridges into islands, which are always very numerous along coasts of this type. The famous Inside Passage from Puget Sound to Sitka, Alaska, is made up of deep waterways, running between countless islands.

Steamers taking this inside passage are in smooth water all the way, whatever may be the weather conditions in the open sea.

Fiord coasts may be among lofty mountains, as in Norway, or in low mountains, as in Scotland, or where the coast line is determined by great series of fault scarps. Typically, fiords have high and steep rocky walls, and to the height of these much of the impressive grandeur of the coast scenery in Norway and Alaska is due. In Norway, Greenland, and Alaska the land valleys in which fiords terminate inland are frequently still occupied by glaciers. In the southeast of Sweden and in Finland, the embayments have all the characteristics of fiords, except that they have low walls, which are sometimes almost at the water's edge. These bays, with low-lying, rocky shores are called *fiards* in Sweden, a term which has been adopted by many English-speaking geographers. Another variant of the type is given by the föhrden of the eastern coasts of Denmark and Schleswig-Holstein, which resemble fiords except in not having their rocky shores.

The writer is convinced that only the glacial theory will satisfactorily account for all the facts regarding fiords. Glaciers, unlike rivers, have the power of "overdeepening" their valleys, that is, to excavate them below sea level, for the ice must continue its erosive work, even after it has entered the sea, until it is so far submerged that it begins to float; and how far the overdeepening may be carried below sea level will depend upon the thickness of the ice, but as soon as the glacier enters the sea, its erosive power is diminished by the buoyant action of the water, and is progressively lessened, as the ice is more deeply submerged, until flotation begins.

It is not at all necessary to assume that the valley was originated by glacial erosion; in most instances, probably, the valleys were pre-Glacial and were formed in all sorts of ways. Some of them have been determined by lines of fault, which frequently determine the location of river valleys, because the faulting often produce masses of shattered rock, which are easily removed. Others began as ordinary river valleys, of which the position and course were primarily determined by the original slope of the land. However formed, these valleys became the channels of ice streams, when the Glacial Epoch had spread its ice sheets over the lands of high latitudes in both hemispheres. The glaciers remodeled the valleys in their own characteristic fashion, over-deepening them, so that the sea would have taken possession of them on the disappearance of the ice, even had there been no depression of the land, or rise of the sea, after the Glacial Epoch. Fiords, then, have all the characteristics of glacially modeled valleys of which the sea has taken possession. They are restricted to the high latitudes of the northern and southern hemispheres and to lands which have been glaciated, a remarkable coincidence if, as has been contended, glaciation has nothing to do with fiords. Fiord valleys are altogether like the glaciated troughs above sea level, and, were they to be raised above sea level, would form a series of lake basins like those in glaciated valleys on the land. As previously pointed out, tributary "hanging valleys," which enter the main valley far above its floor and not at grade, as stream valleys do, are characteristic of valleys which have been modeled and deepened by glaciers, and also characteristic of fiords. If glacial action is not necessary to the production of fiords, it is surprising that fiords should have so many glacial characters.

The fiord coasts of Scandinavia have a great historical interest as a school of shipbuilding and of seamanship. In 789 A. D. appeared the first of the pirate fleets which carried such terror to the coasts of Europe from the Elbe to the Rhone. The succeeding century is called by historians the "Viking Age," and is regarded as ending with the establishment in the north of France of the Scandinavian settlers who became the Normans. The Vikings and their successors were almost unopposed, for even Charlemagne had no navy and the first English king who had warships was Alfred the Great. Away from the Mediterranean, shipbuilding seems to have been a lost art in Europe, except in Scandinavia; and several of these ancient ships have been recovered almost intact in Norway and Sweden, and it is astonishing to reflect what these bold navigators accomplished with such inadequate means. The Scandinavian seamanship was far in advance of that possessed by other Europeans of the period, and the Northmen, as they were universally called, made wonderful voyages, which were not rivaled by other nations for many centuries. In 850 they reached Iceland, which had previously been discovered by Culdees from Ireland, and settled that island soon after the date mentioned. They discovered Greenland, it may be as early as the beginning of the tenth century, and established a colony there in 986, and in the year 1000 Leif Ericson sailed from Greenland to the American mainland, and followed the coast southward to "Vinland," which by some authorities is believed to be Nova Scotia, while others think it is New England.

These are very remarkable achievements and stand in very sharp contrast to the timid coasting voyages which were all that contemporary European sailors attempted. The seamanship which was developed among the Scandinavian fiords and extended in the stormy waters of the North Atlantic, became, in the course of centuries, the common possession of all the northern nations; and the commercial supremacy of England and Holland, though chiefly determined by their geographical situation, was also largely due to the seamanship which they had learned from the Scandinavians.

II. *Coasts of Emergence.*—These are due to land rising from beneath the sea, or, as has sometimes happened, to the withdrawal of shallow seas, laying bare the bottom. Coasts of emergence are straight and regular and have a few or no islands or indentations, for the sea bottom is usually flat or has extremely gentle, almost imperceptible slopes. Whatever irregularities the bottom may have originally had are speedily removed by the action of waves and currents, which wear down projections and fill up depressions, so as to produce a smoothly graded surface. Southern New Jersey and eastern Texas are bordered by coasts of emergence. Whether a coast shall be called one of emergence or submergence, in cases where there have been oscillations of level, first in one direction, then in another, is determined not so much by the direction of the latest movements, as by the balance of characteristic features. The coast of Maine is often cited as a coast of submergence, and all its most striking and characteristic features are due to submergence, and yet its latest movement has been a slight rise. The rise, however, has had but little effect upon the character of the coast. The shores of southern New Jersey and eastern Texas, as already mentioned, are typically coasts of emergence, but the rise was followed by a slight submergence.

III. *Neutral Coasts.*—The term neutral as employed by Johnson (though Supan uses it in a different sense) includes those shore lines whose characteristics are determined by neither submergence or emergence, but by other processes, chiefly of construction. Coasts of this class fall into several distinct subdivisions, in accordance with the process that has made them, though few of them are continuous for any great distance. One such subdivision is the delta coast, made by the deposits which a river builds up at its mouth, and the form of the delta varies greatly in accordance with tides and currents, the amount of sediment discharged, and similar factors. The coast of Italy on the Adriatic side, down to Ravenna, is fringed with almost continuous deltas that have built the land out into the sea from two to twenty miles since Roman times. The rivers that flow to the west coast are almost all small, but the Tiber has built out a considerable delta. Another type of neutral coast is that made by coral reefs, which may be attached to the shore as a fringing reef, or may run parallel to the shore, from which it is separated by a channel, as a barrier reef. Examples of fringing reefs may be seen on a great scale on the east coast of Africa, while the great barrier reef of Australia runs for 1,200 miles. The material for the reef is supplied by coral polyps and other marine animals and plants which secrete the carbonate of lime from sea water, but the piling up of the reef above high tide is the work of the waves. Coral reefs are confined to warm waters and their formation is prevented by cold currents, even in the tropics, which explains their absence from the east side of the Atlantic and Pacific Oceans and their luxuriant growth on the west side of these seas. Finally may be noted as a neutral type of shore line those which are due to faulting, the upthrow side standing in a line of cliffs to make the new coast, while the downthrow block is sufficiently depressed to allow the sea to reach the scarp of the upthrow side. Coasts of this character have been reported from New Zealand.

IV. *Compound Coasts* are those which are prominently characterized by features belonging to two or more of the preceding classes. The coast of North Carolina has oscillated upward and downward in such fashion as to combine the features of coasts of submergence and emergence. The lower courses of the rivers have been drowned and converted into tidal estuaries, which is characteristic of shore lines of submergence. On the other hand, there is the very long and conspicuous offshore bar which separates Albemarle and Pamlico Sounds from the ocean, and such bars characterize coasts of emergence. Some of the New Zealand faulted coasts are compound, for the upthrow block has been depressed and its valleys drowned. The eastern coast of the Asiatic mainland is described by Von Richthofen, Supan, Gregory, and others as a coast of faulting. It is also a coast of emergence, due to tilting of the fault blocks. Deltas are frequently coasts of submergence as well and are then compound.

From the economic point of view, sea coasts are of the utmost importance to the civilized inhabitants of the countries which the coasts border, because the sea is the great highway of communication between different parts of the world. Ocean-going trade must be carried on in keeled ships, and keeled ships should have an anchorage protected from wind and wave for the purpose of loading and unloading. The Mediterranean ships of ancient times, which were chiefly propelled by oars, could be easily hauled up on the beach, and the Greek and Phœnician traders were not so dependent upon ports as are the great vessels of to day. Under modern conditions, the regular, unindented coast is very unfavorable to the development of maritime commerce, though it may not entirely prevent it. The west coast of South America is almost completely devoid of harbors, the ports being merely open roadsteads, where cargo is landed or loaded by means of lighters, when the weather permits. South of Guayaquil no rivers enter the sea, for the coastal plain is a rainless desert, until central Chile is reached, and river mouths are the best harbors. Callao, the principal port of Peru, is one of the best harbors on the west coast; it has safe anchorage in its bay, which is protected on the south and west by a tongue of land, called la Punta, and on the north by two islands. One of the few irregularities of the coast is taken advantage of to make a port, which even in colonial days was a busy commercial center, as it was the only open port south of Panama. Valparaiso, the chief port of Chile, is situated on an open, semicircular bay, the southern promontory of which affords an anchorage protected from the west and south, but not from the north. Southern Chile has a very irregular coast, with countless islands and bays.

The ancient Egyptians, Peruvians, and Mexicans would seem not to have been seamen at all. Even at the present time the eastern coast of Mexico has singularly few natural harbors. Tampico, which has become so important on account of the fabulously rich oil lands of its neighborhood, and Coatzacoalcos have been made into safe and commodious harbors by jetties to scour out the bars which obstructed the rivers on which these towns are built. Vera Cruz was a restricted and dangerous port until protected by the construction of breakwaters. On the Pacific side there are many sheltered bays and good anchorages, but these are largely inaccessible from the interior. That the sea-borne commerce of Mexico and Peru should be almost entirely in foreign hands is not surprising in view of such coastal conditions, under which there is small inducement for men to adopt a seafaring life.

Good harbors are provided by nature, and their location is beyond human power to change; they may be greatly improved, but there must be some natural beginning which is to be improved. The primary purpose of a harbor is to afford a place of refuge for ships, where they can lie safely at anchor and be protected from storms and heavy seas. The best harbors are those where the ships are not only protected, but where the depth of water is such that they can be moored alongside of wharves or quays and take on or discharge cargo directly to and from the shore. Less favorable are the harbors where the ships must load and unload by means of lighters, for this means that the cargo must be handled twice. The lighterage, which is such a heavy tax upon the commerce of New York, is not due to conditions of depth, for the ships are tied up to piers, but to the fact that nearly all the railways have their terminals on the west bank of the river and, at present, railway tracks cannot be laid on the piers of the Manhattan side. It is unfortunate that this magnificent harbor, one of the most commodious in the world, should be under the jurisdiction of different States.

For a harbor to be thoroughly satisfactory for commercial purposes, it must have sufficient depth of water leading from the open sea to the anchorage and wharves, must give complete protection to shipping, and must be capable of receiving and caring for a large number of ships at the same time. It should have a fairly straight channel for the entrance and departure of ships, and should be free from ice. The Atlantic ports of Canada and the harbors of Russia, except those on the Black Sea, are closed for a longer or shorter period every year by ice. Vladivostok on the Pacific has an excellent harbor, but is made inaccessible by ice in the winter. The fact that only the Black Sea ports are available throughout the year makes the Bosphorus and the Dardanelles so vitally important to Russia, and the control of the Straits by an alien, and often hostile, power was of the greatest possible disadvantage to Russia.

A valuable commercial harbor must not only be readily accessible to shipping from the sea, but must also have good communication with the interior of the country which it serves, and be placed at the meeting place of trade routes. What made New York develop into the largest of American cities and the first of American ports, was not only its great natural advantages as a harbor, but the building of the Erie Canal, which, together with the Hudson River, brought to the wharves of New York the trade of a vast interior, including the rapidly growing commerce of the Great Lakes. The Dalmatian coast has many good harbors, but south of Fiume they are, for the most part, inaccessible from the interior, and railways cannot be built to them without prohibitive expense. This fact made the Jugoslavs so anxious to possess Fiume.

Drowned valleys usually make excellent harbors; the character of the drowned valley is, of course, dependent upon the character of the landscape before submergence and upon the amount of the depression. The submergence of a coast line which is flat and bordered by a coastal plain, gives harbors like those of Baltimore and Norfolk. A land surface of greater relief will, on submergence, form harbors like those of New York, Havana, Rio de Janeiro, the harbors on the Maine coast, and those of Puget Sound and San Francisco. The depth of water in the drowned valleys is determined partly by the amount of depression and partly by the amount of sediment which has been deposited in the channels. A surprising amount of mud, several hundred feet in depth, nearly fills up the rocky cañon of the Hudson. The great advantage which drowned valleys usually, but not always, possess, is that not only are they good harbors in themselves, readily accessible from the sea, but also they have convenient access to the interior, whether by the river which has excavated the valley before its submergence, or by the railroads which have so largely been built in river valleys.

Such harbors as those of New York and San Francisco, admirable as they are in most respects, suffer from the drawback of constantly forming shoals from the sediment brought down by the river and carried in from the sea by the tidal currents, and these shoals require frequent dredging. In New York Bay it has been necessary to dredge the Ambrose Channel to a depth of forty feet in order to permit the entrance of the largest modern ships. San Francisco harbor is famous for its beauty, its commodiousness, and convenience, but south of Puget Sound, the Pacific Coast ports have but a narrow tributary country. Beyond the lofty mountain wall which bounds California and Oregon on the east, are vast stretches of desert, arid and semi-arid plains, with a sparse population, which contributes but little to the commerce of the ports. Pacific Coast commerce is thus made up partly of purely local contributions and partly of long distance business, such as the cargoes of silk and tea, which are landed in San Francisco or Seattle and forwarded to the merchants and manufacturers of the Atlantic States. New Jersey is the principal seat of American silk manufacture, and the raw material comes chiefly from Japan and China.

The harbor of Galveston, like the harbors of many small ports on the Atlantic and Gulf coasts of the United States, is formed by a barrier, or off-shore bar. Such harbors have the drawback of constantly shifting sands which must be battled with at great expense and often disappointing results. The inlets to the port behind the barrier beach frequently change their position as the result of heavy gales, and engineering works are powerless to prevent the change.

Boston harbor is a combination of the drowned valley and the barrier-made bay. The protection of the port and shipping against the sea, especially in violent northeasterly gales, is largely accomplished by the islands at the mouth of the harbor.

Large rivers often make excellent harbors, as in the case of New Orleans, Quebec, Montreal, Buenos Aires, Hamburg, Antwerp, and many others. Such harbors have the great advantage of very easy communication with the interior, and form a natural meeting place of inland and maritime commerce. They are perfectly protected from storms; the depth of water, as a rule, is ample; and ships may tie up to the shore, loading and unloading without lighters. The difficulty with such ports is not in the harbors themselves so much as in the approaches to them. The mouth of the Mississippi, for instance, had a natural depth of thirteen feet, while above the delta there was abundant water for the largest ships. Captain Eads secured sufficient depth in the Southwest Pass by constructing jetties, which, by narrowing the river, increased the velocity of its current, putting an end to deposition of sediment on the bar, which was scoured by the swifter current and its material carried down to deep water in the Gulf. This method has the advantage of making the river dredge itself.

The harbor of London is sixty miles from the sea, but the lower Thames is an estuary rather than a river, and the bar at its true mouth is above London, as the bar at the real mouth of the Hudson is but a few miles below Albany. The port of London, like that of Liverpool and Antwerp, has been very extensively enlarged by the construction of an immense series of dock basins, which take advantage of the high tide.

River mouths are very widely used as harbors, particularly on coasts where no other opening is found. The north coast of France is not well supplied with deep-water harbors; the best and most extensively used of them is Havre at the mouth of the Seine, and the chief port of Holland is Rotterdam, at the mouth of the Maas (or Meuse).

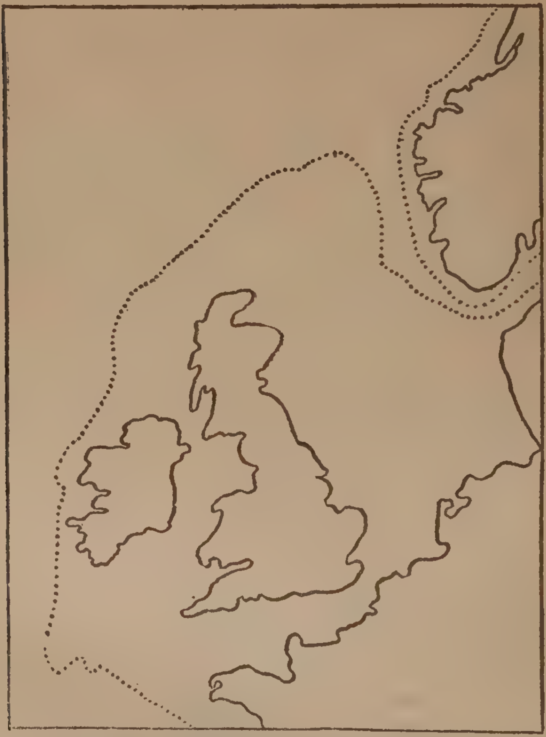
ISLANDS

The islands of the sea number many thousands, but the number of large islands is not very great. Islands fall naturally into two classes, the *continental* and the *oceanic*, which are quite different in their structure, relationships, and history.

1. *Continental Islands* are merely detached fragments of the continent near which they stand and from which they are separated, in almost all cases, by shoal water. For reasons that are elsewhere explained, the limit between deep and shallow water is drawn at the 100-fathom line, and nearly all continental islands rest upon submarine platforms which are under water less than 100 fathoms deep and run into the submerged continental shelf. The geological structure of continental islands is the same as that of the adjoining continents, to which a moderate elevation of the sea bottom would reunite them. It is, in most instances, practicable to determine the geological date of the separation of a continental island from its parent continent by comparing the animals which are found on the island with those of the adjacent continental region. The greater the difference in the animals between the continent and the island, the longer is the time of their separation.

A very familiar instance of a continental island is that of Great Britain, which is separated from the mainland of Europe only by the shallow English Channel. The geological structure of England and Wales is much the same as that found in France and

Belgium, the same sort of rocks occurring in much the same order of succession, while the Highlands of Scotland agree better, geologically speaking, with the Scandinavian Peninsula. The wild animal life is the same as on the mainland, and the fact that the species of animals are the same on two sides of the channel, is an indication that the island was detached from the continent at some



N. W. COAST OF EUROPE SHOWING THE SHALLOW BANK LESS THAN 600′ CONNECTING BRITISH ISLANDS AND CONTINENT time in the present geological period, for quadrupeds cannot swim across the English Channel. Migratory birds, which winter in Italy and northern Africa, pass over the channel twice every year. Bears and wolves are no longer found in Great Britain, but they did exist there for some centuries after the Norman conquest. An old English writer, in what may be called the prescientific period, urged that the presence of these fierce and noxious animals proved a former land connection between the island and the continent, because they could not cross the seas of themselves and no one would have introduced such creatures. The conclusion is a just inference from the facts.

Ireland, also a continental island, was detached from Great Britain somewhat earlier than the separation of the latter from Europe, as it differs more in its animals, but only shoal water separates it from Great Britain, and the submarine platform upon which it rests is continuous with the continental shelf off the coasts of France and Spain. Madagascar was once a part of Africa, but its numerous mammals are so very different from those of that continent that the geological date of its separation must have been much before the time of the detachment of Ireland from Great Britain. The Mozambique Channel, between Madagascar and the continent, is very much deeper than the British seas, which would, of itself, suggest, though not definitely prove, its greater antiquity. Great Britain, Ireland, and Madagascar thus represent islands of three different geological dates of separation from the mainland, and the list might be almost indefinitely extended to form a series of increasing antiquity.

The great Asiatic islands, Sakhalin, Japan, Formosa, the Philippines, Celebes, Borneo, Sumatra, and Java, are similarly detached fragments of Asia, and stand upon extensions of the submerged continental shelf, and their animals indicate that the separation of the various islands from the continent took place at different dates. South of Formosa, the islands named above, together with countless smaller ones, make up the Malay Archipelago, which is everywhere surrounded by relatively shallow water. Even were the geographical relationships of these islands not made clear by the soundings, the animals found in them would be sufficient to show that the islands are detached portions of Asia.

The nature of the Greater Antilles is open to some doubt, and there has been much debate on this problem, a debate which still continues and would seem to be far from settlement. The dispute concerns the question whether these islands have ever been connected with the continent, or have been insular throughout their history. Geologically, they closely resemble Central America, and the axes of their mountain ranges are in line with those of the Central American ranges. So far, their characteristics are those of typical continental islands, but they differ from the usual islands of that class in the fact that they do not stand upon the continental shelf, but rise steeply from profound oceanic depths and are separated from the mainland and from one another by very deep straits; these are characteristics of oceanic islands. These islands, Cuba, Haiti, and Porto Rico, have singularly few native mammals, or quadrupeds, as compared with the great tropical islands of the East Indies. Compare, for example, Cuba with Java; the two islands are of nearly the same size, and have very similar climates, yet, from the zoölogical point of view, the two islands differ remarkably. Java has ninety species of mammals, only five or six of which are peculiar to the island and found nowhere else. The list is a very variegated one and includes a rhinoceros, tiger, leopard, wild dogs, deer, wild swine, monkeys, etc., a fauna as rich as would be found on a corresponding area of the Asiatic continent. Cuba, not including bats, has only four or five species, one an insectivore and the others rodents. This extreme zoölogical poverty is possibly in part due to the interference of man, for the early historians, writing soon after the Spanish conquest, describe several animals of which no trace is left. If these creatures were not imaginary, European settlement must have exterminated them. It is this extraordinary paucity of indigenous quadrupeds, together with the deep-water surroundings of these islands, which has led some students of the West Indies to the conclusion that the islands have never been connected with one another or with the mainland.

There is much to be said on both sides of the problem of the Greater Antilles, but most of the students who have investigated this question have come to the conclusion that the islands were once connected with one another and with the mainland of Central or South America, or with both. The remarkable zoölogical poverty of the islands they would explain by the events of their geological history.

New Zealand supplies an instance of a continental island which is far from any other land, 1,200 miles from Australia. Except two species of bats, New Zealand is not known to have any species of native mammal, though Maori tradition affirms the former presence of a ratlike animal, and a creature resembling an otter has been reported from the south island, but both of these await confirmation. Geologically speaking, New Zealand is like a fragment of a continent and not at all like an oceanic island, but its animals and plants show that it has been separated for a very long time from any other land area with which it may have been formerly connected. Indeed, it is a question whether it ever was connected with any continent, but the available evidence, which is not altogether conclusive, goes to show that at an ancient period in their history these islands were united with northeastern Australia, for a submarine bank like an isthmus, with very deep water on each side of it, unites that part of Australia with New Zealand. The connecting submarine isthmus is covered by fairly deep water, less than 1,000 fathoms, but this does not at all preclude the possibility of a former land connection.

New Guinea, the largest existing island, if Australia be regarded as a continent, was once connected with Australia, from which Tasmania has recently (in the geological sense of that word) been separated. Both Tasmania and New Guinea are typical continental islands.

2. *Oceanic Islands.* The islands of this, the second class, rise from deep water far from any continent, though they may occur in a close group, like the Hawaiian Islands, the Azores, the Galapagos, and many others. Oceanic islands are all either volcanic in origin, or they are coral reefs; but, inasmuch as the so-called reef-building corals cannot live in water which is more than twenty fathoms deep, it is probable that all the reefs are built up from volcanic foundations. Oceanic islands thus

have none of the sedimentary, metamorphic, or plutonic igneous rocks (such as granite) which make up most of the mass of the continents and continental islands. The volcanic islands of the Atlantic, from Iceland to St. Helena, are oceanic islands which, to all appearance, have never formed part of any continent, with the possible exception of Iceland, but are submarine volcanoes which have built up their cones until they have risen above the surface of the sea, sometimes, like the peak of Teneriffe, to great altitudes. The thousands of islands in the South Pacific, which constitute the archipelagos of Polynesia, Melanesia, and Micronesia, are, without exception, of the oceanic type and, for the most part, they are coral reefs. The vegetable and animal products of these oceanic islands show with sufficient clearness that they have not been parts of any continent, but have obtained their animals and plants partly through the action of the winds and the currents of the sea, and partly by other accidents that have occasionally brought them visitors from distant lands, visitors that have been able to establish themselves permanently.

Aside from bats, which can cross wide stretches of sea and are often carried long distances by gales, oceanic islands have no mammals, but the absence of quadrupeds does not indicate that conditions are unsuitable for them. In many islands mammals have been introduced by human agency and have flourished and multiplied exceedingly. Pigs, goats, rabbits, and even cattle have run wild in many oceanic islands and have found the vegetation and the climate admirably suited to their needs. It was, therefore, no climatic barrier or lack of suitable food that prevented mammals from inhabiting oceanic islands, but the impossibility of reaching the islands across the sea. Amphibia also (i. e. frogs, toads, newts, etc.) are absent from oceanic islands, because neither they nor their eggs can endure exposure to sea water. True fresh-water fishes, as distinguished from fishes which readily enter streams flowing into the sea, are lacking in the islands of this class; but birds, lizards, insects, and land shells are very widely distributed among them. Snakes occur but rarely, and this is rather surprising, for snakes have been known to cross as much as 200 miles of sea by swimming. Evidently the zoölogy of oceanic islands affords no support to the old belief that such islands were fragments of vanished continents.

That islands are really thus stocked is not merely a speculation, but has been actually observed. In the year 1883 the island of Krakatoa was devastated and partly destroyed by the most terrific volcanic outburst of which we have any record, and it would seem that not a living animal or plant escaped destruction. Only a few years after the catastrophe, the island had been resupplied with plants and insects by the winds and currents. Krakatoa, it is true, is near both Java and Sumatra in the Strait of Sunda, but that merely explains the rapidity with which the restocking was effected.

From the point of view of human interests, the chief difference between the continental and the oceanic island is a matter of size, for none of the oceanic islands can fairly be called large. Another difference that is not without importance is the remoteness of the oceanic islands from the main lands and the centers of civilization. On the other hand, the continental islands are mostly large, near the main land and, when the climatic conditions are favorable, are well suited for the support of flourishing populations. No better illustration of this fact could be found than is afforded by Great Britain, which has long been one of the leading powers of the world, and has gradually built up a scattered empire so vast that it contains more than one-fourth of the population of the earth. One cannot imagine the origination of such an empire in any of the oceanic islands, such as the Azores, or the Hawaiian group, because they are too small to support the necessary population, and the Pacific islands are too far away for them to have entered actively into the history of civilization, as Great Britain has done in such a remarkable way.

So far as the continental islands are concerned, their history is very largely that of the adjoining continents, though with certain important and significant differences. Islands have a natural defense against invasion, and England has not been successfully invaded since the Norman conquest in 1066. The expedition of William of Orange in 1688, which resulted in his accession to the thrones of the three kingdoms, can hardly be called an exception to this statement, for he met with no military resistance. No continental power in Europe has had such immunity from invasion as that; each of them has in turn been overrun and trampled under foot by hostile armies. To a great extent, of course, England's security has been due to the development of a powerful navy, which has ever characterized the island kingdom, but it was the insularity which led to the development of the navy. The "silver streak" which separates England from the continent (only 18 miles wide at its narrowest point) has made all the difference, and has tended to give England a development quite distinct from, though not altogether independent of, that of the European continent.

For a long time past, the English have been reproached for their insularity, for standing aloof from general European interests, but this insularity is, of course, the effect of their geographical position. They are geographically insular and cannot fail to be affected by that fact. English insularity, too, has led to the development of an unrivaled merchant marine. It was not until the era of trans-Atlantic discovery that England's remarkably favorable position began to tell and enable her to become a great maritime power. She had had but little share in the Oriental trade which had enriched Venice, Genoa, and other Mediterranean ports, but when Columbus and his successors had found their way to the New World and the Portuguese had doubled the African Cape and reached India, England's opportunity came, and she seized it. Then began the great growth of the English marine, both mercantile and naval. When, in 1588, the "Invincible Armada" sailed from Spain, it seemed absurd to hope that Elizabeth could escape condign punishment at the hands of the angry Philip. Yet, when the ponderous Spanish vessels arrived in the British Channel, the relatively light, handy, and easily managed English ships mastered the Armada and put it to disastrous flight. From that time on, England's maritime supremacy steadily rose.

In the seventeenth century England's chief rival in commerce and navigation was Holland, and the difference in population between the two countries was not so very great, but England's larger territory was able to support a very much greater population, which eventually told in giving the great advantage to the island.

On the other side of the world, Japan occupies a very analogous position in Asia to that which Great Britain holds with reference to Europe. In 1624 all the Japanese merchant ships were destroyed, cutting off all, save occasional, communication with the other islands and with the mainland of Asia. In this isolation the Japanese developed a very strong national feeling and individuality and a large and homogeneous population, which pressed hardly upon the resources of the islands. When, in 1868, Japan determined to adopt much of Western civilization, she had prepared herself to make the change very successfully, and has gained a position as one of the great powers and unquestioned leadership among Asiatic peoples. The analogy with Great Britain is shown in the extremely rapid development of shipbuilding and navigation, and the carrying trade of the Pacific is now largely in Japanese hands.

At the very dawn of European history, we find the leadership of Mediterranean civilization was in the island of Crete, in which there arose a culture very different from that of Egypt or that of Asia. Until the arrival of the northern conquerors, who brought to Greece an Indo-Germanic speech and a knowledge of iron, Crete was the leader of the whole Ægean world.

Commerce and navigation are, in a sense, thrust upon islands, many of which have owed all their importance to their position with reference to established trade routes. Islands like Malta, Rhodes, and Delos, played a great part in the ancient world, a part which was entirely conditioned by their situation. When the great Hanseatic League, that powerful federation of North German towns, established itself in the Baltic, it was Wisby in the island of Gothland that became the Scandinavian center of the Baltic trade and the principal depot of the League.

Islands tend to become more densely populated than corresponding areas of the mainland, and, for many islands, this problem of population has become a very serious one. In Barbados the negro population presses hard upon the resources of the island in the matter of subsistence. Porto Rico offers problems of the same sort, distressing poverty being very prevalent among the islanders. The same is true in Polynesia, and the native islanders, before the time of European discovery, had adopted many schemes to prevent an increase of the population. Infanticide, cannibalism, and polyandry were all devices of this nature. The Polynesians developed surprisingly great skill in the art of navigation, far surpassing in this regard peoples who stood high above them in general civilization, the Chinese, for instance. They continually made bold, long-distance voyages, across great, lonely stretches of the Pacific and were able to make charts in which, though the distances were inaccurate, the bearings and directions were remarkably true. Scarcity of food was often the motive for daring voyages, yet it was also the insular situation and command of good harbors that sent these men to sea.

CHAPTER XI

THE OCEAN

WE have made some study of the sea as an agent of destruction, cutting back the coast and sweeping away the land; now we have to consider it from a somewhat different point of view, as a part of the earth's surface, with its own characteristics.

Until comparatively lately, oceanography was a mixture of true and false ideas, good observations and arbitrary assumptions; it was, in the first place, the surveys necessary for the laying of telegraph cables, which were begun in the second half of the last century, and then the expeditions sent out by the various governments, which have given accurate information concerning many features of the ocean, its sides and bottom. Of these expeditions the most important was that of the British naval vessel, *Challenger,* which from 1872 to 1876 sailed 68,690 miles, crossing all of the oceans repeatedly, sounding and dredging wherever she went. Second only to the *Challenger,* has been the work carried on by the vessels of our own Government, especially of the Coast Survey, the Fish Commission, and the Navy. An immense amount of work has been accomplished off our eastern coast, in the Gulf of Mexico, Caribbean Sea, and the Pacific Ocean. In the latter was made the great survey for the cable to Guam and the Philippines.

To be "on soundings," in nautical phrase, means to be on water of which the bottom can be reached by the old hand line with its leaden weight. This ancient device, the use of which is mentioned in the New Testament, is of no service in exploring the deep sea, where depths are measured in miles, and elaborate machines have been successfully devised for sounding the greatest depths, and for securing samples of the bottom and of the sea water at any desired depth. Though the work of deep-sea exploration already accomplished is very great, yet, compared with the vast area of the oceans, the lines of soundings which have been made are not only relatively scanty, but they are very unevenly distributed. The ill effects of this inequality of distribution are, however, lessened because of the flatness of the ocean floor as compared with the topography of the land. Only exceptionally is the bottom relief like that of a land surface. This uniformity of the sea bottom over great areas is largely due to the absence of the destructive agencies, which operate only on the land; in the deep sea the movement of water is only a slow creep, entirely ineffective as a means of denudation. Furthermore, the sea bottom is an area of sedimentary accumulation, which tends to fill in depressions and reduce inequalities. On the steeper submarine slopes, the loose sediment is liable to slips, especially as a consequence of earthquakes, which rupture the cables lying on such slopes. In 20 years Milne reported 245 breaks in 38 lines of cable.

The materials that gather on the ocean bottom change very much with the depth of water and nearness or remoteness of land. On the submerged continental shelf, the seaward margin of which is usually, but by no means always, demarcated by the 100-fathom line, gravel and sand are the principal deposits, with mud in the deeper holes. The width of this submerged shelf varies greatly on different coasts; off the Atlantic shore of the United States, from New York southward, the shelf is more than 100 miles wide, while on the Pacific side of both North and South America deep water begins within ten or fifteen miles of the shore. The relatively steep slope of the continental platform is covered with muds of various colors which, like the sand and gravel of the shoal-water belt, are derived from the wear and waste of the land. In profound depths the ocean floor is covered with organic oozes and vast areas of the oceanic red clay. The oozes are made up of tiny shells of microscopic animals and plants and are, in some cases, calcareous or limy, in others siliceous or flinty. The excessive slowness with which these deep-sea deposits are accumulated is shown by the proportion of meteoric dust, derived from outer space, which these deposits contain, and likewise by the fact that bones and teeth of whales and sharks which have long been extinct, still lie uncovered on the ocean floor and have been repeatedly brought up in the deep-sea dredges.

Many volcanoes exist in the sea; in addition to the volcanic islands described in the preceding chapter, it is known that many active submarine vents exist, but it is not possible to estimate their number, for to catch a submarine volcano in the act of eruption is a matter of fortunate chance. Certain volcanic products, notably pumice stone, float for weeks or even months, and are carried immense distances by ocean currents before they become water-logged and sink. Whether derived from land or submarine vents, volcanic materials are very widely spread over the sea bottom, and the oceanic red clay, which covers such vast areas in the deepest parts of all the oceans, is derived from the decomposition of pumice.

In describing the forms which the ocean basins would display, and the topography of their sides, if all the water could be removed, international geographical congresses have adopted certain terms which it is desirable to use in the interests of a uniform and exact nomenclature.

On the floor of the deep ocean two general topographic features, *elevation* and *depression*, are admitted. Of depressions three kinds are recognized: (1) the *basin* is approximately round; (2) the *trough* is an elongate and broad depression; and (3) the *trench* is long and narrow and lies along the edge of the continental platform; the deepest part of a depression is called a *deep*, and those which are more than 3,000 fathoms in depth have received names. Three types of elevation are distinguished: (1) the *rise* is very gentle in slope; and (2) the *ridge* is steeper and narrower than the rise; (3) the *plateau* is a submarine table-land, rising steeply from a surrounding depression. The highest part of an elevation is called a *height*. These are the major features of deep-sea topography, and there are some minor forms so important as to require names. These are (1) the *bank*, which is not more than 100 fathoms, nor less than 6 fathoms, below the surface, and (2) the *reef* or *shoal*, which has less than 6 fathoms of water over it; reef is generally used for ledges of hard rock, and shoal for loose material, usually sand, but usage is not always consistent. Finally, a *furrow* is a narrow groove which crosses the continental shelf.

The continental shelves are the submerged margins of the great continental blocks or platforms, which rise steeply from the ocean floor; the submergence of the shelves has taken place in geologically recent times, and differs greatly along different coasts in the width of the submerged area. These shelves, then, are land surfaces modified by the smoothing action of the sea in planing down projections and filling up depressions, but the many furrows which are still preserved are river valleys, cut when the shelf was land. The Hudson, the Congo, the Niger, the Ganges, the Golden Gate furrows are the best known, but there are great numbers of others. Large depressions of the continental shelf give rise to fringing and internal seas, such as the North and Baltic Seas; the former has an average depth of only 51 fathoms, and the latter is still shallower, with an average depth of 30 fathoms. In the western part of the Baltic are furrows more than half a mile wide and 20 fathoms or more deeper than the adjoining parts of the sea. On the outer, or seaward, side, the continental shelf often plunges steeply down into very deep water, but the steepness of this slope varies greatly in different places. The average slope of the continental mass seaward from the margin of the shelf on the western shore of Europe is 13 degrees or 14 degrees, but in places it is very much steeper than that. Where the French cable, running from Brest to New York, passes down the continental slope, the angle is 30 degrees to 41 degrees, grades as steep as those encountered in the Alps. Could the ocean floor be laid bare, an observer standing on that floor would see the continental block rising more or less steeply in different regions, and the upper edge of the block, where now is the submerged margin of the continental shelf, would have an average height of 13,116 feet, more along some shores, less along others. The trenches are frequently found at the foot of the continental slope and are frequently, if not always, formed by faulting and tilting of the blocks. A trench generally has one side, that toward a continent or an island very steep, while the side toward the sea has a gentler slope. All the soundings, hitherto made, which are of more than 4,000 fathoms, are in trenches, and thus the profoundest depths of the sea are in the neighborhood of land, rather than in mid-ocean. While the highest points of the land are nearly as high above sea level as the deepest points of the sea are below that level, the *area* of great elevation of the land is very much smaller than that of corresponding depths in the sea.

A few details regarding the conformation of the bottom in one of the oceans will be instructive. The Atlantic Ocean, North and South, is divided into two depressions by a central rise, which begins off Iceland and at 51 degrees N. latitude expands into what Lieut. Maury, the famous oceanographer of our navy, named the Telegraph Plateau, which seemed placed to facilitate the laying of the first Atlantic cables. Thence, the rise continues to the Azores Plateau, which has very well-defined inequalities of surface, and it has been traced to 55 degrees S. latitude, giving a length of 7,500 miles. The depth of water on the rise is 1,000 to 1,500 fathoms. On each side of the rise are troughs, which widen into basins; the western trough expands northward into the North American Basin, the deepest part of which yet discovered is in the Porto Rico Trench, 4,561 fathoms. Southward, the trough widens into the Brazilian Basin, great areas of which are below 2,500 fathoms, and the maximum sounding, 4,030 fathoms, is in the Romanche Deep, almost on the Equator. The trough on the eastern side of the Central Rise is not so deep, though the North African Basin, around the Cape Verde Islands, has deeps of 3,300 fathoms, and soundings of more than 2,700 fathoms have been made in the Bay of Biscay. Near the Azores a depth of 3,284 fathoms has been found in what is called the Peake Deep.

Imagining the Atlantic bed as a land surface, we should find it by no means devoid of surface relief and diversification, but the features are very broad and simple and change but slowly. The Central Rise would appear in the distance as a low mountain wall, from 6,000 to 10,000 feet high, with even sky line, like the Appalachian ridges, but with much more gentle slopes on the sides. At two points the rise expands into plateaus, but elsewhere is quite narrow. The volcanoes, Iceland, the Azores, Madeira, the Cape Verdes, the Canaries, St. Helena, and Ascension, seen from the ocean bed, would be very lofty peaks or groups of peaks, many of them exceeding 20,000 feet in height. The troughs and basins would form exceedingly flat plains on each side of the Central Rise, with very gentle slopes and changing but slowly from point to point, and broken here and there by the elongate, narrow, and steep-sided trenches, which are rift valleys, or depressions formed by tilted fault blocks. Save for the volcanic cones, no mountains have been brought to light by the sounding line, though the structure of the Central Rise can only be conjectured. In the broad simplicity of its topography the floor of the Atlantic Ocean is unlike any known land surface.

It is not necessary to take up the other oceans, for they merely reenforce the conclusion which the Atlantic suggests, namely, that their deep floors have never been land. Narrow, isthmuslike land connections may have extended where now is deep sea, and some such connections are suggested by rises and ridges which are not covered by truly oceanic depths of water. One such connection which is made exceedingly probable by many independent lines of evidence is that between South America and Antarctica, by way of the Falkland and South Shetland Islands. Another indicated connection is the rise which separates the Arctic from the North Atlantic basin and connects the Faroe and Shetland Islands, Iceland, Greenland, and North America. Over this rise the water seldom exceeds 300 fathoms in depth, and there is strong reason to believe that in the distant geological past a land bridge connected Europe and North America along the line marked by the rise. Geologists of great authority, including the late Professor Suess, of Vienna, have held that the North Atlantic was formed at a comparatively late period in the earth's history, and that for ages its site was a land area. This is not the place to discuss a geological theory which the present writer is unable to accept; it is mentioned here merely to show the wide diversity of opinion which obtains.

To the geographer and the historian the Mediterranean is of particular interest, because for ages all civilization, save that of the Far East, was concentrated in the lands around that great inland sea, and its geological history is better known than that of any other similar body of water. The Mediterranean is separated from the Atlantic by a ridge which extends from Cape Spartel, the northwestern angle of Morocco, to Cape Trafalgar, in southwestern Spain, and on this ridge the depth nowhere exceeds 175 fathoms, but east of this ridge the water deepens very rapidly. The Balearic Basin, which is the part of the Mediterranean between Spain on the west and, on the east, the rise on which Corsica and Sardinia stand, has a maximum depth of 1,742 fathoms, and the Tyrrhenian Basin, between the Sardinian Rise and the Italian coast, is nearly 2,000 fathoms deep. From Italy and Sicily to Cape Bon in Tunis there is a rise, most of which is less than 100 fathoms deep, and nowhere does the depth reach 200 fathoms. The Eastern Basin has large areas which are more than 2,000 fathoms deep. At a former geological period, Spain was a peninsula of Africa and was cut off from Europe, and the western Mediterranean was connected with the Bay of Biscay by a strait through southwestern France. Italy was connected by land with Tunis, and thus the two great basins of the Mediterranean were completely separated; one result of these changes is that, zoölogically, north Africa belongs to Europe and not to Africa south of the Sahara.

Aside from the movement of the waves, the surface of the sea represents the true shape of the earth, assuming that form under the combined action of gravity and centrifugal force. The level of the sea is not, however, constant, because of the tides, which are produced by the attraction of the moon and, in less degree, by the sun. The tides occur twice in the course of a lunar day of 24 hours and 50 minutes, so that there are two periods of high water and two of low water in every lunar day. According to the mean solar time, the tides are about 50 minutes later each day than they were the preceding day, though the interval is variable according to the age of the moon.

The tide is a wave that passes around the earth from east to west, following the apparent path of the moon in the heavens; the wave is better developed in the southern hemisphere, where the Antarctic Ocean rolls unbrokenly around the earth. The continents greatly modify the force and direction of the wave, and the shallow water near shore retards it, so that the crest may be in the latitude of Newfoundland, while the margins are in the West Indies and on the coast of north Africa.

The tides are not uniform from day to day, but change in the amount of rise and fall in accordance with the relative position of the moon, sun, and earth, and whether the attraction exerted by the sun and that by the moon cooperate with each other, or are antagonistic; the solar tide is about one-half the lunar. On the day after the new moon, the sun and moon are on the same side of the earth and nearly in line, and their combined attraction, operating in the same direction, produces a maximum, or *spring tide;* and on the day after full moon, when the sun and moon are again in line, though on opposite sides of the earth, we again have a spring tide. On the day after the first and after the third lunar quarter, the tide is at a minimum, or *neap tide,* the solar and lunar attraction being then antagonistic. Spring tides have a range nearly three times as great as neap tides.

Still another cause of variation in the tides is to be found in the fact that the moon's path around the earth is such that during a certain part of every lunar month it is nearest to the earth, and at a certain other part it is farthest away, the difference between the two positions being about 1/10. Since the force of attraction varies greatly with the distance (inversely as the square of the distance) the tides will be highest, other things being equal, when the moon is nearest the earth, or, in astronomical phrase, "in perigee."

In the open ocean the tidal wave is not perceptible, one reason for which is that there is nothing with which to compare it. As the wave approaches the land and begins to be modified by the form of the sea bottom, the range of the tides is very greatly affected, the great local differences which are observed being due to the form of the coast and the contour of the sea bottom near shore. The Bay of Fundy is famous for the immense rise and fall of its tides, which are attributed to the funnellike form of the bay, with broad mouth, rapidly narrowing inland. The advancing tide is piled up, as it is continually crowded into a narrower space, until the rise may amount to 60 feet. Even on the open coast, near the mouth of the Bay, at Eastport, Maine, the range of the tides is unusually great, 29 feet. Similar phenomena present themselves in Bristol Channel and the estuary of the Severn, in England; at the mouth of the channel, the range of spring tides is 18 feet, and at Chepstow, on the Wye, two miles above its junction with the Severn, it is 50 feet. The coast of Patagonia is also remarkable for the great range of its tides, which exceeds 50 feet; no other open coast in the world has so great a range.

The remarkable tides on the coast of Great Britain are due to the insular character of the land and the different character of the surrounding seas. The tidal wave passes up the Atlantic to the northern end of Scotland, and also begins to run up the English Channel. The Channel is narrow and shallow, and the tide is retarded in its passage; the part of the wave that went around the north of Scotland has entered the North Sea, where the two branches of the wave meet.

The presence of islands off the coast, around which the tide passes, produces differences of level, higher on one side at high water and on the other side at low water, thus causing tidal "races," as they are called, flowing like a swift, reversible river, in one direction at high water and in the opposite direction at low water. This is well shown at Hell Gate, New York, where the East River makes a junction with Long Island Sound. The tide flows westward through Long Island Sound and northward from Sandy Hook up New York Bay, but it rises higher in the Sound and therefore, at flood tide, there is a swift tidal race from the Sound into the East River and thence into the Bay; at ebb, the race is in the opposite direction, from the East River into the Sound. At the mouth of Buzzard's Bay, Massachusetts, very swift and powerful tidal races are produced between the Bay and Vineyard Sound. The Sound is open at both ends and the tide sweeps freely through it, rising a foot or so higher than in Buzzard's Bay, which is a *cul de sac*, closed at the northern end. There is, therefore, a powerful race into the Bay at flood tide and out again at ebb. Tide races may thus be due to differences in the height of the tide, or in the time of arrival of the tidal wave at the two points affected.

The tides are of very great practical importance, because the movement of shipping into and out of a harbor is very largely dependent upon the state of the tide. Sir Robert Ball says: "If the moon were suddenly to be struck out of existence, we should be immediately apprised of the fact by a wail from every seaport in the Kingdom. From London, from Liverpool, from Bristol, we should hear the same story. The rise and fall of the tide had almost ceased; the ships in dock could not get out; the ships outside could not get in; and the maritime commerce of the world would be thrown into dire confusion." Anyone who has spent an impatient night at anchor in the lower Scheldt, waiting for the tide to take the ship up to Antwerp, or has been held up in some very large ship to cross the bar at Sandy Hook, or at the mouth of the Mersey, will appreciate the importance of the tide.

Salinity. As everyone knows, sea water is salt, and the peculiar salty, bitter taste of the water is due to the substances which are dissolved in it and which amount to thirty-five parts per thousand by weight. Thirty-two of the chemical elements have been detected in sea water, and this number will probably be increased by future investigation, but most of the substances are present in exceedingly minute quantities. For example, sea water contains gold, and this undoubted fact has more than once been made the basis for swindling operations. Of the thirty-five parts of dissolved substances, more than twenty-seven are common salt (chloride of sodium) and the chlorides of magnesium and calcium, and the sulphate of calcium, or gypsum, make up nearly all of the remainder. The chlorides of magnesium and calcium must be most carefully and painstakingly removed in the process of refining table salt, for very small quantities make the salt bitter to the taste and cause it to absorb moisture from the air, so that it becomes damp and sticky. Pure chloride of sodium is free from these objectionable qualities. The composition of the sea water is almost the same in all latitudes and longitudes of the open sea, though the calcium content increases slightly with depth. The salt content increases slightly from the equatorial zone poleward to the belt of 15 degrees—35 degrees, N. and S. latitude, for in that belt the steadily blowing, fresh, and dry trade winds cause a rapid evaporation, and hence the salt content of the surface layers of the sea water is somewhat greater. North and south of the trade wind belts, toward the poles, the quantity diminishes.

In the more or less inclosed seas conditions are very different, and such seas may be salter than the open ocean, or less so, according to circumstances. The Baltic Sea is much fresher than the ocean, especially its upper end, where the water is brackish because of the large amount of river water which is there discharged; in the western part of the sea, the water has eight parts of dissolved substances per 1,000 of water; in the Gulf of Bothnia, the proportion is less than three, and in the Gulf of Finland, less than one. The Black Sea has somewhat similar conditions, but the water is salter, fifteen to eighteen parts per 1,000. The Mediterranean has somewhat more salt than the ocean, thirty-seven parts per 1,000, because it receives relatively few large rivers and most of its surface is in a warm, dry climate, where evaporation is rapid. In the Red Sea, where the temperature is high and evaporation very quick, the maximum of solid content is reached, forty-one parts per 1,000. Into both the Mediterranean and the Red Sea there flows a surface current from the ocean, and below this is an outward counter-current.

Temperature. The temperature of the sea, so far as the surface layers of water are concerned, is primarily dependent upon latitude, for the heat is all derived from the sun, and the internal heat of the earth, in this connection, is entirely negligible. While latitude is thus very important in determining temperature, its effects are greatly modified by the ocean currents. In general, the surface temperature of sea water is rather higher than that of the lowest layers of air which are in contact with the water, but the yearly range of temperature of the water is considerably less than that of the air. With the exception of the polar seas, the ocean temperatures show the following arrangement. There are, first, a surface layer, about 100 fathoms deep, in which the temperature diminishes rapidly downward; secondly, a middle layer of 350-400 fathoms depth, in which the downward decrease continues, but more slowly; and, finally, the bottom mass, which may be several thousand fathoms deep, and is of almost uniform temperature and salinity. In its upper and middle layers the South Atlantic is considerably colder than the South Pacific or Indian Oceans, while the North Atlantic is considerably warmer than the North Pacific. The surface layer reaches its maximum of temperature in the equatorial belt, and diminishes in heat northward and southward from that belt.

In the neighborhood of the continents, on the submerged shelf, the distribution of temperature in the sea is more or less irregular, being chiefly determined by local conditions. It changes with the seasons, and is affected by winds and currents, but in the true ocean depths there is much more regularity. Here a temperature of 40 degrees F. is reached at the depth of a few hundred fathoms, but below that the diminution is extremely gradual until 32 degrees F., the freezing point of fresh water, is reached. Over a very large part of the ocean bottom, including even the equatorial regions, the temperature is from 32 degrees to 35 degrees F., while temperatures of 31 degrees have been recorded, especially in the southern oceans. Everywhere the deep sea is uniformly and monotonously cold and dark, and with but a creeping movement of the water. Even in bright, clear seas, such as the Mediterranean, the last trace of sunlight, as registered by a photographic plate, disappears at about 325 fathoms; probably no light would be visible to the eye at considerably less depths. It seems that this distribution of temperature in the deep sea, the extreme cold even in the equatorial zone and under the direct rays of the tropical sun, is due to the slow creep of the water along the bottom. At the equator the water near the surface is warmed, expands and rises, flowing poleward along the surface; in the polar regions the water is chilled, in consequence of which it becomes more dense and sinks. If the earth were stationary and not rotating upon its axis, and if there were no continents to interfere with the flow of water, these movements would result in a very slow circulation, consisting of a surface flow from the Equator poleward, and a very slow creep along the bottom from the polar seas toward the Equator. Even with the modifications introduced by the earth's rotation and the presence of the land masses, the theoretical circulation above described is substantially what actually happens, save that most of the cold water in the oceanic depths comes from the Antarctic Sea, because the Arctic Sea lies in a closed basin, connected with the North Pacific only by the narrow and shallow Bering Strait, and demarcated from the North Atlantic by a rise which nowhere has more than 300 fathoms upon it. This would prevent any free interchange of bottom water between the Arctic Sea, and the Atlantic or the Pacific. There is no such obstacle to the influx of bottom water from the Antarctic Sea, into which the South Atlantic and Pacific open in undiminished depth.

In the more or less land-locked seas the temperature relations are determined by the depth of water at the entrance to the sea from the ocean. Thus, the Mediterranean, though very deep, is connected with the Atlantic by a relatively shallow passage, the Strait of Gibraltar, where the depth is only 200 fathoms. Consequently, in the Mediterranean, the bottom water is no colder than the water at the depth of 200 fathoms; and, while on the Atlantic side the bottom temperature is 35 degrees F., on the Mediterranean side it is 55 degrees, the same as at 200 fathoms. This, and other instances of the same sort, give very strong confirmation to the inference that it is the bottom creep from the polar seas, especially the Antarctic, which produces the uniformly cold water of the oceanic depths.

Waves.—The waves are generated by the friction of the wind as it blows over the surface of the water, and therefore increase in violence as the velocity of the wind increases, so that the power of the waves in severe storms is almost incredible. Experiments carried out many years ago by the Scotch Lighthouse Board showed that the wave pressure on the coast of Scotland averaged, for the six winter months, 2,086 pounds per square foot, and that in storms the pressure rose to more than 6,000 pounds on the same unit surface. Structures, such as sea walls, breakwaters, lighthouses, which are put up to withstand the fury of a stormy sea, must not only be built with the utmost possible strength, but must be designed with a clear understanding of the manner in which storm waves do their work of destruction. At North Beach, Florida, a block of concrete, weighing more than two tons, was moved 12 feet and turned over on its side. At Cherbourg in France, blocks of stone 3½ tons in weight were carried over a wall on the embankment 20 feet high. At Wick, in the Orkney Islands, at the end of the breakwater, was a mass of concrete of 800 tons which was tied by iron rods of 3½ inches in thickness to great foundation stones, making a mass of 1,350 tons, which was washed inside the pier in December, 1872. It was replaced by a block of 2,600 tons, and this was swept away by a storm in 1877. Waves may run up a sloping surface and cause damage far above sea level. At the Trinidad Head lighthouse on the Pacific coast, in December 1913, a storm wave rose to the lantern, 196 feet above high-water mark. On the Oregon coast, waves shooting up more than 200 feet have been observed, and in the Shetland Islands of Scotland the waves burst open a door 195 feet above tide. In view of such destruction, it might seem hopeless to attempt the building of structures to withstand the sea, yet it has been successfully accomplished many times. On all coasts lighthouses are built on shoals and reefs that have long resisted all the sea can do;

breakwaters, like those of Cherbourg in France and Dover on the south coast of England, continue to protect the harbors which they inclose, despite the utmost fury of the waves. Correct design and solid construction are the secrets of success.

The protection of coasts against the sea presents other problems, which have as yet been solved with only partial success. In England these questions have assumed such a serious aspect, that a Royal Commission was appointed to study them and stringent regulations have been adopted, limiting the control which landowners may exercise over their own seaside property, because injudicious interference with natural conditions has sometimes resulted in damage and destruction.

The eastern coast of England has been retreating for centuries past before the attack of the sea. The character of this coast is such that the destructive work of the waves has a maximum effect; it is a steep and abrupt shore, rising boldly from the water, and yet composed of quite soft rocks, which yield readily to the undermining action of the surf. On the Yorkshire coast the rate of recession of the land varies, in different localities, from 7 to 20 feet a year, and in Suffolk as much as 45 feet in a single year. The reports of the Royal Commission on Coast Erosion, and many other English publications, contain a great mass of details upon the destructive action of the sea, which it is impossible even to abridge here. Immense sums have been spent in the construction of sea walls and other devices, to protect the east and south coasts of England from the sea, but with only partial success, such structures often failing when attacked by exceptionally severe storms. When a storm wave strikes full upon the vertical face of a sea wall, part of the wave is hurled high into the air and the masses of water, falling heavily upon the land behind the wall, may wash it out and wreck the wall by removing its backing.

Flat and low-lying coasts, like our own Atlantic shore south of Rhode Island, are less rapidly removed than high and steep coasts, though one would expect that the surf would wash away loose sands much more quickly than solid rock. Between Seabright, N. J., and Sandy Hook, a narrow sand spit, on which runs the N. J. Southern Railroad, separates the sea from the so-called Shrewsbury River, and often in the winter storms the spit is breached and the railroad line wrecked for longer or shorter distances. The sand bluffs south of Long Branch, N. J., have frequently been so cut into as to destroy the houses built on them; and sea walls which have been put up to protect limited stretches of private property have usually been made to collapse by undermining and washing out the sand and gravel on which they are built. It has been found that the most effective protection which can be given to this low shore of loose sand is to build bulkheads of heavy planking, spiked to piles, which run *across* the beach to a little below low-water mark, and thus present only their narrow edges to the blow of the waves. These bulkheads catch and hold the sand as it moves down the coast, propelled by the waves, the undertow and the tidal currents, and are often soon buried out of sight under masses of sand, thus preventing the removal of the land and building it out at the expense of the sea.

The city of Galveston, Texas, is built on a low sand-spit, Galveston Island, which is 28 miles long and varies in width from 1½ to 3½ miles. On

September 8th, 1900, a terrific West Indian hurricane, in which the wind attained a velocity of 135 miles per hour, piled up the Gulf waters to a height six feet above the previous high-water mark (i. e., that of September, 1875), and huge waves swept across the lower part of the city, drowning 5,000 people and more or less completely destroying 8,000 buildings. As Galveston is the most important cotton exporting seaport in the United States, there could be no question of abandoning the site, but only of protecting the rebuilt city. The first step was to raise the grade of the whole town by amounts varying from 1 to 15 feet, and the second to protect this raised area by a great sea wall of concrete, facing the Gulf of Mexico, from which side comes the danger to be apprehended from the tropical hurricanes. This wall is five miles long and rises 17 feet above the sea; it is 16 feet thick at the base and 5 feet at the top; at the foot of the wall is a protecting apron of granite "rip-rap," to prevent undermining.

Ocean Currents.—In addition to the tides and the waves, the ocean has a regular system of circulation by means of currents. The cause of these currents has been much debated, but there is now quite general agreement that they are due to prevailing winds. As in all fluid bodies, there can be no empty spaces in the sea, and as soon as any quantity of water, however small, begins to move, its place must be taken by other water, which, in turn, must be replaced by still other water, until the whole sea is involved and a closed circulation is set up. Then, too, the deflecting effect of the earth's rotation must be taken into account, for any current in the northern hemisphere is deflected to the right, and in the southern hemisphere to the left. The

Gulf Stream is a typical example of the ocean current and, while exaggerated statements have been made regarding the effects of the Gulf Stream, it is, nevertheless, a factor of importance climatically along the coasts of Norway and Scotland, keeping the harbors of these coasts free from winter ice and mitigating the winter cold on the land.

In the North Atlantic there is a slow drift of water toward the equatorial portion of South America, where it divides, the smaller portion flowing southward and the larger part northward, still as a slow drift. Part of this northward drift passes outside of the West Indies, while another portion passes into the Caribbean Sea and thence between Cuba and Yucatan into the Gulf of Mexico, where it circulates around the Gulf and flows out of Florida Straits as the Gulf Stream. This now strong current flows northeastward almost to the European coast, where it divides into two parts, a northern part which subdivides into three branches, one going to the coast of Norway, the second passing west of Iceland, and the third entering Baffin's Bay. The southern part flows to the northwest coast of Africa as the Canaries Current, and most flows back into the Northern Equatorial Current.

This is the type of ocean current which is repeated, with modifications, in all of the oceans. A similar encircling current, the Brazilian, flows in the South Atlantic; in the North and South Pacific and in the Indian Ocean are circuits of the same sort. The Kuro-Siwo (Black Stream), or Japan Current, pursues a course very like that of the Gulf Stream.

There are a few cold currents in the northern oceans. The Arctic Current flows down the east coast of Greenland, and the Labrador Current comes down out of Baffin Bay to the Banks of Newfoundland, where its meeting with the warm waters of the Gulf Stream produces almost continuous fog. The cold current then turns southwestward along the coast of New England, making the waters of that coast cold, even in summer, as far south as Cape Cod. A similar cold current flows from the Arctic Sea through Bering Strait into the North Pacific. Into the southern seas there is a vast movement of cold water from the Antarctic Ocean, besides a great current around the earth in that ocean itself. The cold Benguella Current flows up the west coast of Africa, chilling the ocean, and the Humboldt Current carries cold water along the west coast of South America almost to the Equator. There is a great contrast in temperature in a coasting voyage on the east or west coasts of Africa and South America; along the west coast the sea and air are cold, but very warm on the east coast, making a notable difference in the comfort of the voyage. Coral reefs are strictly limited by temperature and, roughly speaking, occur between the twenty-eighth parallels of north and south latitudes. On the east coast of Africa they are developed on a great scale, also on the West Indies and the coast of Brazil; but on the west side of both continents the cold currents prevent the establishment of reefs.

Ocean Commerce.—The ocean is an excellent illustration of the way in which the value and significance to mankind of geographical features may be radically changed by the advance of civilization. To the barbarian the sea is an impassable barrier, for though the Polynesians have acquired a surprising degree of skill in seamanship and navigation, they are exceptional people in this respect and their achievements have no bearing upon the history of civilization. Even to the men of high civilization in the lands around the Mediterranean in classical and mediæval times the ocean was a thing of dread, to be avoided whenever possible. To modern nations ocean-borne commerce is their lifeblood; and the interruptions of that commerce in the World War by the blockades on one side, and the ruthless submarine campaign on the other, have had a most disastrous effect upon all European lands. To the modern peoples the oceans are the great highway of commerce, and all the continents and the islands of the sea are bound together by regular lines of navigation. Even countries like Switzerland, which have no seacoasts and no ships, nevertheless carry on extensive importing and exporting ocean trade, making use of the ports and ships of their neighbors. The struggle of Jugoslavia for Fiume, and of Poland for Danzig, is occasioned by the belief that access to the sea is vital to the life of a modern nation. When Austria was still a great power, her control of the outlets of Serbia's trade put that country completely at her mercy, as Chile holds Bolivia by the throat, for Bolivia has no seaport and Chile controls the railway leading to the Pacific coast.

The civilization of the ancient world was Mediterranean, leaving aside the Oriental empires which had but little direct influence upon the West. Even Persia, Mesopotamia, and other Asiatic powers were continually pressing forward to gain a foothold upon the Mediterranean shores. Ancient history is, to a very large extent, the story of the struggle for commercial advantage and political power in the Mediterranean. The Egyptians left maritime trade in other hands, and when written history begins, the great merchants who dominated the commerce of the inland sea were the Phœnicians, though the Greeks became their serious rivals and planted colonies and trading stations as far west as Marseilles, which was originally a Greek settlement. Then power was transferred to the West and the rivalry of Carthage, originally a Phœnician colony, and Rome filled the center of the stage. By slow degrees the Roman power spread over all Italy and continued to expand until the Empire took in all the lands bordering on the Mediterranean, with the addition of what is now Hungary, southern Germany, Gaul, and Britain. When the barbarian invasions destroyed the Western Empire in the latter part of the fifth century, the Eastern Empire, with capital at Constantinople, continued. The establishment of Germanic kingdoms in Gaul, Italy, Spain, and northern Africa, did not greatly change the routes. Trade was still chiefly Mediterranean and few mariners ventured into the Atlantic. Another important route was between India and the African coast, sometimes by coasting voyages to and from the Red Sea and the Persian Gulf, partly direct voyages which took advantage of those remarkable reversible winds, the northeast and southwest monsoons. This eastern trade entered the Mediterranean world by the Red Sea and Egypt, or by the caravan routes of Persia, Syria, and Asia Minor, and the wares were chiefly such as had small bulk or weight and high value, such as spices and silk.

As the kingdoms founded by the Teutonic invaders became more civilized and orderly, European commerce began to add the inland and fringing seas of the north to its domain. English sailors and merchants made extensive use of the North Sea and the Baltic, finding sturdy rivals in the traders of the "Low Countries," which are now Belgium and the Netherlands, and in the powerful Hanseatic League, a federation of German towns which dominated the Baltic and, less completely, the North Sea. The Italian city republics, notably Venice and Genoa, rose to great wealth and power by their control of the Adriatic and the eastern Mediterranean. The rise of Mohammedanism and the Saracen conquest of Palestine, north Africa, and Spain, which led to the Crusades, did not stop commerce in those lands, and throughout the Middle Ages European commerce was a traffic of the inland and fringing seas, the Mediterranean, the Baltic, and the North Sea. The Turkish conquests brought about radical changes in trade routes and forced the European nations to betake themselves to the ocean, for the Turks, who cared nothing for commerce, hindered the trade with the East, but did not altogether stop it. The Turks were forced to migrate from central Asia by the pressure of the Mongols and established themselves on the eastern shore of the Mediterranean, from which they overran and held all the lands of the eastern Roman Empire. Constantinople itself fell in 1453, and the conquering march of the Ottomans continued until the whole Balkan Peninsula, including Hungary and Roumania, save only a strip of the Dalmatian coast and gallant little Montenegro, Asia Minor, Syria, and Mesopotamia to the Persian Gulf, Egypt, and the north coast of Africa had been added to the Turkish Empire. Venice was driven out of Greece and the Greek islands, and in 1683 even Vienna was besieged, and only the great military skill of John

Sobieski, King of Poland, checked the invaders. With the shutting off of the eastern commerce Italy swiftly declined.

It became necessary to find new ways to the Indies, and this forced men to the oceanic route, for no other was left. In the pioneer work of discovery Portugal, under the leadership of Prince Henry, called "the Navigator" (1394-1460), took the lead. Exploring voyages led to the rediscovery and colonization of the Azores, which are more than 800 miles from the nearest point in Europe, and of Madeira. But Prince Henry's chief preoccupation was with Africa, and he sent ship after ship down the west coast of that continent in the hope that it might be doubled and a way found into the Indian Ocean; but though much progress was made, the Prince died long before Diaz discovered the Cape of Good Hope and at last reached the Indian Ocean (1488). Ten years were still to pass before Vasco da Gama succeeded in reaching India, thus turning the flank of the Turkish obstacle and opening a new era in European commerce. "The glory attaching to the name of Prince Henry does not rest merely on the achievements effected during his own lifetime, but on the subsequent results to which his genius and perseverance had lent the primary inspiration. To him the human race is indebted in large measure for the maritime exploration within one century (1420-1522) of more than half the globe, and especially of the great waterways from Europe to Asia both by east and by west." (H. R. Beazley.)

In the meantime Columbus had persuaded the court of Spain to equip the expedition of 1492, which had resulted in the discovery of America, and this was speedily followed by the English voyages under the Cabots, the French under Verrazano, and, after an interval of some years, by the expeditions under Cartier, which led to the discovery of the St. Lawrence River. Thus the era of the inland seas, of the Mediterranean, the Baltic, and the North Sea, was followed by the oceanic era, when the great highways of commerce were transferred to the ocean. This transfer had far-reaching effects upon the European nations and gave ever-increasing power to the countries which bordered the Atlantic, Spain, Portugal, France, and England. In view of the inactivity of the Italian governments, which could not possibly regard with favor the transfer of the Oriental trade to the Atlantic route, it is remarkable that Italian sea captains took such a leading part in the great discoveries of these stirring times; Columbus for Spain, John Cabot for England, Verrazano for France, were all Genoese by birth, though Cabot was a Venetian by training and naturalization. Spain was the first to make conquests and establish colonies in the New World, and Spain's rise to the foremost place among European states was largely due to the wealth of gold and silver which Mexico and Peru sent across the sea. The Portuguese Empire was established for the most part in Africa and the East Indies, where a monopoly of the spice trade was enormously profitable. The seventeenth century was marked by the rise of England and Holland to the first place in commerce and navigation. The Dutch drove the Portuguese out of nearly all their East Indian possessions and succeeded them in the monopoly of the spice trade. The North American settlements of England, France, and Holland were begun about the same time, but the wars of the seventeenth and eighteenth centuries gave all North America, north of Mexico, to the nations of English speech, Jefferson's Louisiana Purchase in 1803 finally extinguishing French interests in this continent. Thus the development and perfecting of ocean navigation has had the most profound and far-reaching effect upon the history of the various European states, and it was what took place in central Asia, probably climatic change and increased aridity, which drove the Turks westward, that brought about the transfer of the main commercial routes from the inland seas to the ocean. Like the ever-widening rings that radiate from the center of disturbance when a stone is thrown into a pond, the waves of change spreading from the raids of nomads in central Asia broke, centuries later, upon the shores of distant America.

CHAPTER XII

VOLCANOES AND EARTHQUAKES

VOLCANOES and earthquakes are manifestations of forces which are due, not like the phenomena of the atmosphere, running water, the sea and such agencies, to energy derived from the sun's radiation, but to the earth's own internal heat. It was shown in Chapter I that we have very good reason to believe that the deep interior of the earth is very hot, and know to a certainty that it is heated along definite lines. Much, however, remains to be accomplished in the way of explaining the manner in which the earth's internal heat displays itself, just how it produces the earthquake and the volcano, and what is the connection between these two kinds of manifestations.

I. VOLCANOES

The old geographies used to define a volcano as a "burning mountain," or as a "mountain that gives out fire and smoke, ashes and lava." Almost every item in these definitions is erroneous, though they still continue to influence the conceptions that many people cherish on this subject. There is no fire or combustion of any importance in volcanic action, and the mountain, if present, is the result of volcanic action, being the pile of material which has been ejected from the vent. A volcano, then, is an opening into the earth's interior, through which various highly heated substances, molten, solid, or gaseous, are ejected. This definition does not cover every known kind of volcano, but nearly so.

The number of active volcanoes now in existence cannot be definitely determined, for it is often impossible to tell whether a given vent is dormant or extinct. A volcano may remain quiescent for many hundreds of years and then break out with tremendous violence. All tradition of the volcanic nature of Vesuvius died out long before the first recorded eruption, which took place in 79 A. D. Strabo, the Greek geographer, who lived in the time of Augustus, did, it is true, infer from the nature of the rocks at the summit that the mountain was volcanic, but in the seven centuries or more that had elapsed since the colonization of that coast by the Greeks no eruption had occurred. Since that first known eruption, ever famous for its having destroyed Herculaneum and Pompeii, there have been long periods of dormancy, but since the great eruption of 1631 the volcano has not been entirely quiescent. The more active volcanic regions of the earth have been known to Europeans but a few centuries, and hence the distinction between dormant and extinct cannot be made with any assurance. The beautiful Mount Rainier, in the Cascade Mountains of Washington, still has hot vapors issuing from the crater, and yet the cone is so deeply gashed and seamed by erosion as to indicate that it has not erupted for a very long time. The vapors may be merely a dying phase of activity and there may never be another eruption from that vent. Thick masses of extruded volcanic material may retain their heat for an incredibly long period of time, as is well exemplified in the Yellowstone

National Park, the marvels of which, the geysers and hot springs, the paint pots and mud volcanoes, are due to the heat of the uncooled masses of lava which were extruded some millions of years ago. The hot vapors of Mount Rainier are, therefore, no sure sign that the volcano is not extinct. The volcano of Santa Maria, in Guatemala, was supposed to be extinct, but in 1902 broke out with most destructive and devastating violence. A very long list might be compiled of volcanoes, which after centuries of quiescence have erupted with great violence, while others, like Stromboli (one of the Lipari Islands, northwest of Sicily), long remain in constant activity. Stromboli has hardly ceased its action in the last 2,000 years.

Of vents which are known to be, or strongly suspected of being active, there are about 300 to 350 at the present time; and of these two-thirds are on islands and the remainder on the continents. This number does not include submarine volcanoes, except those which have built their cones above sea level and so appear as islands. Submarine vents are known to exist, but there is no way of determining or even estimating their number.

Active volcanoes are not arranged haphazard on the earth's surface, but according to certain very definite laws. They form long linear series or belts; and of these volcanic belts there are three principal and two or three subordinate ones. A volcanic belt is not occupied by vents equally spaced apart, nor do all parts of the belt have volcanoes; a longer or shorter line of vents is succeeded after an interval by another linear series, and when all these series are connected together they are seen to be parts of one line, all having the same more or less sinuous or curvilinear direction. This is well illustrated by the western American belt, which runs from Alaska to the Antarctic region, everywhere following the mountain ranges and running parallel with the coast lines. The Aleutian Islands are largely volcanic, and the Aleutian, Alaskan, and St. Elias ranges contain a dozen vents that are known to be active. The mountains of British Columbia, though continuations of those of Alaska, have no volcanoes, and the ranges of Washington and Oregon have none that are known to be active, though in the Cascade Mountains are many exquisitely symmetrical, snow-capped cones, which are of obviously volcanic formation, but, with the exception of Mount St. Helens, have not erupted since the settlement of the country by Europeans. Mount Rainier and Mount Hood are famed for their extraordinary beauty. Lassen's Peak, in northern California, has been active recently, and there is reason to think that St. Helens, Washington, which erupted in 1841 and 1842, may be only dormant, but this is very uncertain. From the volcanoes of California to those of Mexico there is a long interval without vents, although in Arizona and New Mexico there are many well-preserved cones, mostly small, which are extinct.

The Central American vents, which are relatively numerous, do not belong in the western American, but to a subsidiary belt, that of the West Indies, but the Andes of South America continue the belt after the Central American interruption and contain many active volcanoes; the loftiest South American peaks are volcanic. The belt terminates with the vents of the Antarctic region, where it meets and unites with the western Pacific belt, the two together encircling the Pacific Ocean. The west Pacific or east Asiatic belt pursues an even more sinuous course through the islands that border the coast of Asia into those of the Malay Archipelago, the islands of the South Pacific, New Zealand, and finally Antarctica. This belt is made up of numerous short, curved bands, and in many instances, as off the coast of Japan, and running parallel with the Aleutian Islands, are troughs of great depth ("deeps"), in the ocean floor and near the land—an association which is too frequent to be accidental.

The third belt follows the rise in the bed of the Atlantic, which divides that ocean into eastern and western depressions. From Iceland to Ascension the rise is crowned with groups of volcanic islands, some of which, like Iceland, the Azores, and Teneriffe, have active vents; and others, like Madeira and St. Helena, have only extinct ones. Of this Atlantic belt all the vents, both active and extinct, are on islands, none on the main land of Europe or Africa.

A subsidiary but greatly interrupted belt is transverse in general direction to the three belts above described. The volcanoes of Central America are arranged in east-west rather than north-south lines, and are continued by the vents of the West Indies, the active ones of which are on the smaller islands, such as Martinique, St. Vincent, etc., not in the Greater Antilles. Keeping the same east-west direction is the subsidiary Mediterranean belt, which runs parallel with the great mountain axis of southern Europe. Only one active volcano, Vesuvius, is on the European continent; but, as late as 1538, Monte Nuovo, which is in a large area of extinct vents, the Phlegræan Fields, erupted with considerable violence. Etna is on the island of

Sicily, and the Lipari Islands, north of Sicily, have the remarkable Stromboli, while Vulcano, of the same group, which emits vapors, so-called "smoke," is dormant. Farther east, in the Greek islands of the Ægean Sea, are volcanoes, notably Santorin, which are still active. There is reason to think that the Central American-West Indian band, and the Mediterranean band, may be widely separated parts of the same belt. North of the Alps, from France to Hungary, is a band of extinct volcanoes parallel with the active Mediterranean series.

Considering its great size, Africa is singularly free from active volcanoes; there are great lava fields of geologically late date, such as those of East Africa and the lower Zambesi River, and there are volcanic mountains, such as the Ruwenzori range, Mount Kenia and Mount Kilimanjaro, the latter rising 19,000 feet above sea level and forming the highest point in Africa. The volcanoes of the Great Rift Valley still show some feeble activity.

At the present time volcanoes are so generally on islands or in mountain ranges of the coastal region that the inference has been drawn by several students of vulcanism that the neighborhood of the sea is essential to volcanic activity. Without entering into the very obscure and difficult problems of volcanic action and its causation, it will be sufficient to point out that the very numerous volcanoes, now extinct, of Utah, Arizona, and New Mexico, as well as those of East Africa, were as far from the sea during their period of activity as they are now. Since that period there have been no very extensive changes of the coast lines.

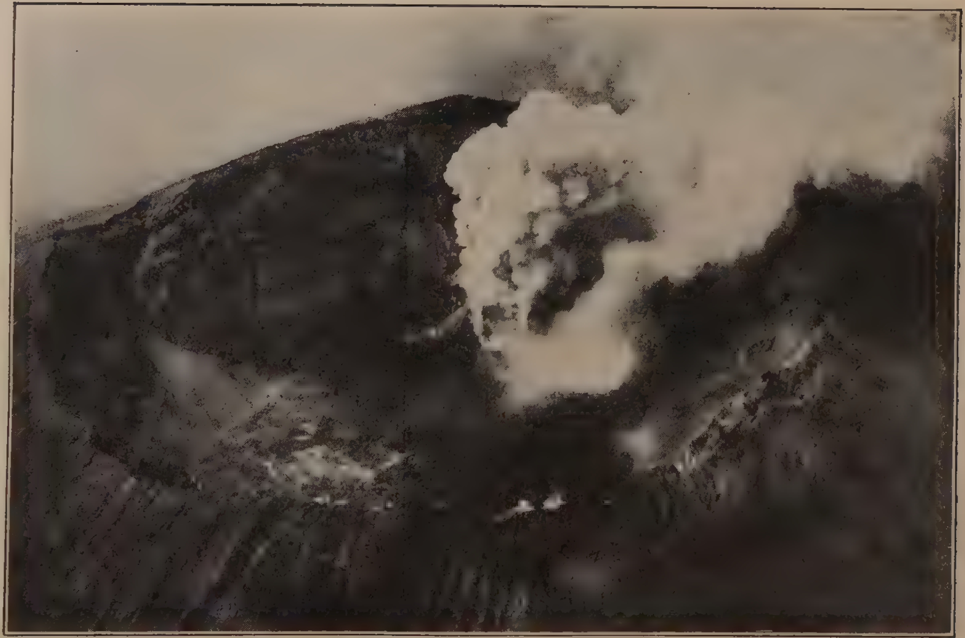
It is evident from what has already been said and much that might be added, that volcanic activity has frequently shifted its place. Aside from the geologically most ancient rocks, which are in so many respects problematical, we find great areas which have never been visited by volcanic action. For example, no trace of such action has been detected in the Great Plains, and in the Mississippi Valley, in the restricted sense, it has always been unimportant. At a very far distant period of geological time the Connecticut Valley, northern New Jersey, central Pennsylvania, Maryland, and Virginia were the scene of volcanic action on a great scale, but the action died out long ages ago and has never been renewed. The plateau country, which lies to the west of the Rocky Mountains and comprises New Mexico, Arizona, Utah, and Wyoming, has had very extensive volcanic fields, and one of the largest lava plateaus in the world covers southern Idaho, eastern Oregon and Washington, where no trace of such activity remains. All of the continents and most of the larger islands have been visited by volcanic action at one time or another, but Africa and the main land of Asia of the present time display very little such action, though the Asiatic islands have still a great many active vents. Any theory of volcanic action which is at all satisfactory must account for this frequent change of position of the vents and explain how it came about that regions which once were volcanic, like Scotland, or the north of Ireland, or the Connecticut Valley, should now be separated by hundreds or even thousands of miles from the nearest volcanoes.

New Volcanoes.—In further illustration of the shifting of volcanic centers there may be given a brief account of volcanoes which have, within historic times, broken out in places where before there was no volcano. Some of these new vents have appeared as new islands in the sea, and in most of these instances it is not possible to say more than that a submarine volcano of unknown age has built its cone up above sea level and made its appearance as a new island. Many instances of this sort have been observed and recorded. A group of these islands, called the Bogoslofs, north of the Aleutian Islands of Alaska, have appeared above the sea at various dates. The first made its appearance in 1796; the second one was first seen in September, 1883, but the exact date of its emergence above sea level is not known. The third, a very large island, appeared between the other two and was seen for the first time on May 28, 1906, as a mass of jagged lava covered with a great number of small craters, which were giving out clouds of steam. In the Ægean Sea is a group of islands collectively called Santorin, in which volcanic activity has been going on for more than 2,000 years; the outer islands are fragments of the rim of an ancient crater, but inside of the ring thus formed are several small islands which rose above the water in 186 B. C. and in 1573, 1707, and 1866 A. D. In all of these instances, and many others which might be cited, were it worth while to do so, only the date of the appearance of the *island* above sea level can be fixed, while the age of the volcano which made the island is unknown. There is one case, however, in which the time of the first opening of the vent on the sea floor has been ascertained. In the year 1831, southwest of Sicily, a violent submarine eruption was observed, followed by the appearance of a new island, where soundings had previously given a depth of 100 fathoms of water; in a few weeks the island grew to a height of 200 feet above sea level and attained a diameter of a mile at the water's edge. It was, however, merely a temporary island, for it was built of fragmentary material, uncompacted, and as soon as the eruption ceased the surf attacked the island and swept it away, leaving a shoal.

On the land many new volcanoes have been formed within historic times, and of some of these very full accounts have been given by eyewitnesses. Monte Nuovo, west of Naples, was formed by an eruption which began on September 29, 1538, and lasted a week, building up a hill 440 feet high and in appearance not distinguishable from the surrounding small volcanoes of the Phlegræan Fields, which were known to Virgil. According to tradition, Fuji-san, the famous volcano of Japan, originated in 286 B. C., and had its last eruption in 1707; its highest point is more than 12,000 feet above the sea. "The remarkable grace of this mountain's curve—an inverted catenary—makes it one of the most beautiful in the world and has obtained for it a prominent place in Japanese decorative art." Many new vents have broken out in Mexico at various times. Of these the most famous is Jorullo, which began in 1759, at a distance of 120 miles from the sea and 35 miles from the nearest other volcano, and continued in activity for several years, building up a group of cones, one of which is 1,300 feet high. In 1871 a new volcano appeared in Camiguin, one of the Philippine Islands north of Mindanao; it continued active for four years, when its cone had reached a height of 1,900 feet.

With the exception of Fuji-san (if we may trust the tradition of its origin), all of the newly formed volcanoes mentioned in the foregoing paragraphs

LIVE CRATERS ON THE VOLCANIC MOUNTAINS BROMO AND SEMERU, IN THE ISLAND OF JAVA



Copyright, Keystone View Co

A VIEW OF THE CRATER OF VESUVIUS FROM AN AIRPLANE have been short-lived; their periods of activity have lasted for a week or a few months, or in some instances as long as four years. When it had once ceased, the activity has not been renewed, and to all appearances the new vents have become extinct, though of course they may at any time burst out in renewed activity. It is impossible to speak with certainty on this point. One volcano of modern formation shows that such short-lived activity is not necessarily associated with the newly formed vents. On the Pacific coast of the Central American Republic of Salvador, north of San Salvador, the capital, the volcano Izalco (or Isalco) broke out for the first time in 1770, and has been in almost continuous activity ever since.

The Phenomena of Eruption differ so much in different volcanoes and in the same volcano at different periods, even within historic times, that the observer's first impression is that entirely different forces must be at work in the different vents, but a wider experience leads to the conclusion that in all cases the agencies are the same and that the differences are due to modifying circumstances. Some volcanoes, like Stromboli, are in more or less continuous eruption, and in such vents the action is relatively so gentle that it is safe to sit in the crater and watch it. Such continuous activity is, however, very exceptional; most volcanoes have periodically recurrent activity, long periods of quiet, broken by violent eruptions, but the periods of rest and activity are not rhythmical or of even approximately uniform length; they vary by thousands of years. A rough correspondence between the length of dormancy and the violence of the next succeeding eruption has been noticed, but there are many exceptions.

While different eruptions would appear in the extreme instances to have almost nothing in common, they are all connected by imperceptible gradations and form an unbroken series from one extreme to the other. As types of one extreme of volcanic action may be taken the great vents of the Hawaiian Islands, Mauna Loa and Kilauea. Though Kilauea is a great opening on the flank of Mauna Loa, the two vents seem to be entirely independent of each other. The crater of Kilauea is a deep pit, of irregularly elliptical shape and about seven miles in circumference; the floor is of solidified, or "frozen," lava, but subject to movements that are not reassuring to the tourist, for at intervals of a varying number of years the crater is drained of lava and the floor sinks, it may be for several hundred feet, and then slowly rises again. In the floor are one or more lakes of boiling lava, one near the southwestern wall, called Halemaumau, is the most constant. This lake sends up jets and fountains of molten lava to heights of thirty or forty feet and, by constantly splashing over its margin, has built up a low containing wall. Sometimes the side of the cone has given way under pressure of the lava and allowed a stream to pour down to the sea.

The crater of Mauna Loa is nearly 10,000 feet higher than that of Kilauea, and the lava seldom pours out of the crater. At long and irregular intervals it either quietly melts its way through the mountain side, or bursts through violently. The level at which the breach occurs determines the height of the fiery fountains in which the escaping lava rises; in the great eruption of 1868 the lava fountains were over 1,000 feet high and, when seen by night from ships at sea, the whole eastern side of the island seemed to be on fire. The lava streams flow for fifty miles before solidifying, though the surface of the lava stream rapidly freezes into a slaggy, cindery crust, which is a remarkably bad conductor of heat and long conserves the heat of the interior of the mass.

What especially characterizes the Hawaiian volcanoes is that their eruptions are not explosive and eject only streams of lava, without any of the fragmental products, such as dust, ashes (erroneously so called) lapilli, or blocks, which are lavishly ejected in the modern eruptions of most of the other active volcanoes. It is not a coincidence that these volcanoes, which emit only lava, should produce a lava remarkable for its fluidity, being hardly more viscous than honey.

At the other extreme may be placed the volcanoes in which the eruption is of the violently explosive type. In such eruptions no molten lava is extruded, but finer and coarser fragments of the solidified lava, for the explosion takes place *within* the lava body and disrupts it. The explosion is due to the sudden and violent expansion of the hot vapors and gases which are contained within the lava. The more important products of this explosive violence are (1) large blocks, often weighing many tons and belonging to any class of rocks, for they are torn off the walls through which the volcanic pipe or chimney has been driven; (2) scoriæ, or cindery pieces like those which form on the cooling surface of a lava stream; (3) volcanic bombs, bits of viscous or pasty lava, blown out of the crater with a rapid movement of rotation, which gives them a rounded form and often makes them hollow; (4) lapilli, pieces of hardened lava, like nuts in size and shape; (5) volcanic ash, so called because the material looks like fine ashes, but a misnomer, because ash is the incombustible remnant of something that has been burned, like the ash of wood or coal, which is not true of volcanic ash; (6) volcanic dust, the finest and most impalpable particles in the ejected materials. Between ash and dust there is no definite line of separation. Under the microscope ash and dust are seen to be tiny fragments of volcanic glass, or bits of the minerals which make up the lava.

A very long list of explosive eruptions might be cited, but three or four will answer every purpose. In 1888 the Japanese volcano Bandai-san which, tradition reports, had been dormant for 1,000 years, had a single explosion of terrific violence, which blew away more than half of the mountain. The most tremendous volcanic explosion that has occurred within historic times is probably that of Krakatoa in 1883. Krakatoa is a small island in the Strait of Sunda, between Sumatra and Java, of which the last recorded eruption had been in 1680. On May 20th, 1883, a great cloud of steam was observed over the island, but the great explosion occurred in August and blew away most of the island, leaving but a third of its original area and bringing depths of 100 to 150 fathoms of water where there had been land. The gigantic force of the explosion produced waves in the atmosphere, which passed around the whole earth and were observed in Berlin ten hours after the explosion. The vast disturbance in the bed of the sea produced enormous waves which, rushing up on the shores of Java and Sumatra, overwhelmed innumerable villages and drowned many thousands of people. No lava was extruded; the ejected material was all fragmentary and of incredible quantity, ashes being distributed over 300,000 square miles and filling up some stretches of water that had an average depth of 117 feet, and such quantities of pumice were discharged and floated so thickly upon the sea, that only the most powerful steamers were able to force their way through it. Most surprising of all was the fact that the finest dust was shot so high into the upper atmosphere that it remained suspended for many months and gradually made its way around the world. Krakatoa dust fell in London and was identified by microscopic examination.

A terrible eruption of the explosive kind occurred in May, 1902, from Mount Pelée in the French West Indian island of Martinique, which had certain features not observed in any other volcano. There had been several preceding eruptions which did no very great damage, but on the morning of May 8th a great black cloud, heavily weighted with incandescent dust and fragments, rolled down the mountain side with the speed of an express train over the city of St. Pierre, which it wiped out instantly and, with one single exception, utterly destroyed the whole population of 30,000 and burned the ships in the harbor.

The year 1902 was a remarkable one in the Central American and West Indian region for the great number and violence of its earthquakes and volcanic eruptions. Besides Mont Pelée and La Soufrière, Izalco, in Salvador, which had been quiet for more than a year, renewed its activity, and in Nicaragua the volcano Masaya broke out. Far more important was the tremendous outbreak of Santa Maria, in

Guatemala, a volcano which had, up to that time, been regarded as extinct.

The first recorded eruption of Vesuvius, which took place in the year 79 A. D. was likewise of the purely explosive kind. The first warning of the coming catastrophe was a series of earthquakes in 63 A. D. which violently shook Campania and so damaged Pompeii that the inhabitants seriously considered the abandonment of the site. It is evident that the work of repairing and rebuilding was going on at the time of the final catastrophe, and that in some of the public buildings the work had not even been begun.

The ejected material which covers Pompeii is only 18 to 20 feet in thickness, and is in two layers. The bottom layer, the first shot out of the volcano, is made up of the rounded, nut-like fragments which the geologist calls lapilli, and the upper and thicker layer is a fine ash.

It will be observed that in all of the examples of violently explosive action cited in the foregoing paragraphs there has been a long antecedent period, usually many centuries, during which the volcano has been altogether quiescent.

Most volcanic eruptions belong in neither of the categories described, but show an intermediate or mixed sort of activity, and extrude all sorts of volcanic products, lava, fragmental materials, blocks and bombs, ash and dust, as well as the various vapors and gases.

Vesuvius gives off lava streams which sometimes flow out of the crater and sometimes burst their way through the side of the cone, which opens in vertical fissures. Explosions are frequent, sometimes moderate, sometimes extremely violent, scattering fragments in all stages of subdivision and grade of coarseness and fineness over an area which is determined by the violence of the explosion and the velocity of the wind. Vesuvian eruptions are always accompanied or followed by heavy rains, which convert the hot ash and dust into mud-flows that often flow down the mountain sides more quickly spread farther, and do more damage, than the true molten lavas themselves. Most volcanic eruptions resemble those of Vesuvius in ejecting both lava and fragmental material, and in building up a mountain which is neither a lava dome, nor a cinder cone, but a compound of both. The main mass is of fragmental substances, coarse and fine, from large blocks to minutely divided dust, but with numerous lava flows that poured down over the sides of the cone, and dikes, or vertical walls, of solidified lava that filled the cracks and fissures which radiated from the central pipe.

The coarse fragmental materials which are ejected from a volcano fall to the ground within a few miles of the vent; they travel such distances because many of them are shot out obliquely, instead of being hurled directly upward. Fine materials, on the other hand, are transported very long distances by the wind, and are often laid down in unmixed deposits far from the volcano which sent them forth. Disregarding such extreme and remarkable instances as that of Krakatoa, it is nothing uncommon for fine volcanic dust to be carried 1,000 miles by the wind. In Kansas and Nebraska are beds of volcanic ash, twenty to thirty feet thick and entirely pure, without the admixture of any other sort of material, which are at least 400 miles from the nearest possible point of supply, and these are not unusual instances.

From the point of view of human interests, one might well be tempted to think that volcanoes were unmitigated evils. Every now and again the world is transfixed with horror to hear that some unexpected eruption has wiped out so many thousand human lives and reduced tens of thousands to hopeless poverty. Speaking of the immediate effects of the eruption of Santa Maria in Guatemala in 1902, Sapper says: "By the hail of stones, lightning strokes, and the falling of houses, a number of people were killed, which I estimated at 500, but which, according to several newer estimates, must be raised to 1,000. Countless buildings were, in some cases, completely buried, in other cases so covered with the ejected masses, that they completely or partially collapsed; many aqueducts were choked by the materials thrown out and, in some districts, the natural water courses as well. Many bridges fell under the burden of the ejectamenta, the roads were buried, and the plantations of every sort were either completely covered up, or severely damaged. * * * Even in Socornosco, nearly 60 miles distant from Santa Maria, more than one-third of the coffee crop was lost; for long distances the pastures were buried, so that the cattle had to be driven to undamaged regions." The direct money loss was estimated at six and a quarter millions of dollars. "The indirect effects of the volcanic outbreak upon the human inhabitants of the region affected were of manifold kinds. The sanitary conditions of the areas, which had formerly, in large part, been very healthy, were essentially changed for the worse. First, dysentery appeared in desolating fashion, probably caused by the content of rotting substances in the river waters; some rivers, like the Rio Melendrez, spread far and wide from their turbid floods an almost intolerable odor of putrefaction. Malaria increased in alarming fashion. * * * The ash particles floating in the air caused inflammation of the lungs and eyes, etc. The volcanic outbreak destroyed far fewer human lives by its immediate effects than it did through its indirect effects."

So far, the description has been one of unredeemed gloom, and yet there are some mitigating facts to set on the other side of the account. In the first place, volcanic action is but one aspect of a process, the ascent of molten masses from the earth's interior toward the surface, to which we owe, directly or indirectly, almost our whole supply of useful metals. The destruction wrought by modern volcanoes is a part of the price we are called on to pay for our iron and copper, our tin, lead, zinc, our silver, gold, and platinum. In the second place, the soils which are formed by the decomposition of volcanic materials, especially the finely subdivided ash and dust, are of extraordinary fertility. The hard, stony lavas give rise to similar soils, but decomposition affects them much more slowly. The dwellers on the flanks of Vesuvius return as soon as the eruption is over, and work to reestablish their devastated fields and vineyards. No peril or risk can induce them to abandon those fabulously rich soils. The volcanic soils of the Hawaiian Islands are notoriously rich, as are the soils of volcanic islands generally. Finally, the advance of knowledge concerning volcanoes will, one may be assured, lead to a system of forecasting volcanic eruptions, so that the endangered population may be taken to places of safety.

EARTHQUAKES

Most people have an instinctive and unreasoning faith in the stability of the earth beneath their feet, and are shaken more mentally than physically by the first strong earthquake in their experience. Yet, in truth, the "solid ground" is very far from stable; somewhere or other the earth's surface is always quaking, and there is no point of which it can assuredly be said that it will not be violently shaken. The statistics collected are, of necessity, incomplete, because two-thirds of the earth's surface, where the sea covers the solid crust, cannot be kept under continual observation and, even on the land, it is only in regions where especially equipped observatories are set up, that a systematic record of the lighter shocks can be kept; elsewhere, they often escape attention. The imperfect lists of earthquakes, as we have them, give an average of 3,830 earthquakes a year, which means that somewhere the earth's surface is perceptibly shaken once in every two hours and seventeen minutes; violent quakes occur, on the average, about once a month in regions which are carefully watched, a number which may be confidently expected to increase as more and more of the earth's surface is kept under continuous observation.

A map on which earthquakes are indicated by shading, so that the depth of tint would show the frequency and strength of the shocks, immediately makes it plain that, like volcanoes, earthquakes are not scattered haphazard over the earth, but arranged in a very definite way with reference to the great surface features of the globe. Their distribution is in very large degree coincident with that of volcanoes, but is, nevertheless, sufficiently different to prove that the two sets of phenomena are not necessarily associated, and that earthquakes occur in regions which are far from any volcano.

Earthquake regions, like the volcanic, are long and narrow belts, one of which follows the west coast of the Americas, from Alaska to southern Chile, but with many interruptions. British Columbia, Washington, Oregon, Lower California, the northern part of the Mexican coast, and the Isthmus of Panama, all are seldom visited by earthquakes, and no violent ones have been recorded there. From this Pacific coast belt is given off a loop which runs along the north coast of South America, through the Windward and Leeward Islands and Greater Antilles to Jamaica and the eastern end of Cuba, though much the greater part of that island is outside of the earthquake area. The second belt borders the western side of the Pacific Ocean, running down through Kamchatka and islands which border the eastern shore of Asia, but not involving the mainland, and thence following the islands to Polynesia and New Zealand.

So far, the coincidence between the distribution of volcanoes and that of earthquakes is obvious, but even in those belts there are some discrepancies. For example, the part of the California coast which has most frequently been shaken, namely from San Francisco south, has no volcanoes which are known to have been active within the human period, and for long stretches there are no volcanoes of any kind. On the whole, however, the coincidence is very close, but in the third belt there is a very much greater difference between the two classes of phenomena. The third belt follows a somewhat irregular course, but, in general, it is equatorial in direction, and is transverse to the belts which encircle the Pacific. It seems to be interrupted by the Atlantic and Pacific, but may, nevertheless, be continuous across the beds of those oceans; information concerning such continuity around the whole earth is still lacking. In the western hemisphere the transverse belt is represented by the loop already referred to, along the north coast of South America and through the West Indies, but in the eastern hemisphere it appears on a gigantic scale. The south of Spain and Portugal and the northwest coast of Africa are outliers of this belt, as are the Pyrenees and the south of France. Italy and the Alps begin an earthquake belt which runs into central and eastern Asia, covering the Balkan Peninsula, Asia Minor, and the Levant. From Persia eastward it divides and sends one branch through central Asia and another around Afghanistan, across northern India almost to the Pacific Ocean. East of the Mediterranean there is a vast area of earthquake country, where, for thousands of miles, there are no volcanoes. Japan, Greece, and Italy are the countries of most frequent earthquakes.

An earthquake is the disturbance appearing at the surface of the earth, caused by some sudden shock in the earth's interior and propagated through the rocks by a series of elastic waves, like the waves of sound, from the point, area, or line of origin. It is the cropping out at the surface of the ground of these waves, and the movements of the loose, inelastic soil, that give rise to the visible phenomena of the quake. So long as the elastic waves are traversing the hard and solid rocks, they travel at a high speed and are very regular, but when they reach the surface and pass into the soil the movements become very irregular and confused.

The phenomena of earthquakes are of unending variety, differing in accordance with the number, duration, and violence of the shocks and their distance from the place of origin within the earth. As these varying factors are never twice alike, and as further variations are introduced by the differing arrangements of rock and soil, the great variety of observed phenomena is not surprising, yet, with all their variety, earthquake phenomena differ only within relatively narrow limits. One of the greatest of earthquakes of modern times is that which shook northern India in 1897 and is known as the "Great Indian Earthquake."

A great earthquake usually begins suddenly. A rumbling sound, rising to a loud roar, accompanies or slightly precedes the movement of the ground, which is described as being first a trembling, then a shaking, and finally a rapid swaying, wriggling motion, in which a given point will describe a figure 8, which is extremely destructive to the buildings. In the open country, when it is violently shaken, it is often impossible to keep one's feet, and many people are afflicted with nausea. The surface of the ground has been repeatedly observed to rise into low, very swiftly moving waves, on the crest of which the ground cracks open, but closes again in the troughs. In a forest so shaken the trees sway violently, as the earth waves pass under them, like a wheat field in the breeze. In mountain regions the violent shaking of the surface often produces great slides of earth and rock, which bring down vast quantities of débris from the heights into the valleys. In northwestern Greece, the earthquake of

1870 caused gigantic rock slides. In all of the very violent quakes cracks and fissures open in the ground, which may subsequently close, or may remain open permanently, and may show a lineal, curved, zigzag, or radiating arrangement. Through these fissures great quantities of sand and water are, in many cases, forced up from below, and form little sand-craters ("craterlets"), or water-filled funnels, on the surface. These are among the characteristic and often repeated features of great earthquakes on whatever land they may occur.

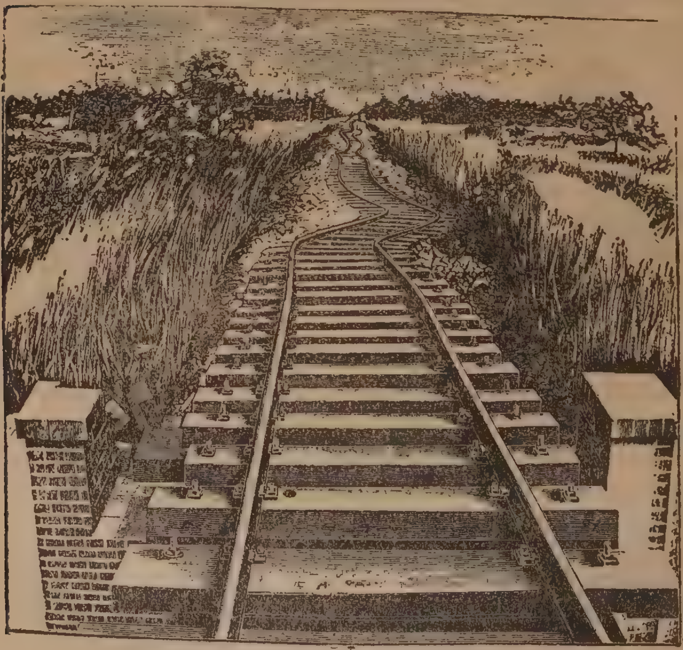
Earthquake fissures frequently become faults or dislocations; on one side of the line of fracture the ground is raised, and on the other depressed, so that a line of bluffs or cliffs, the fault scarp, stands out boldly as a proof of the dislocation. In Owen's Valley, California, along the eastern base of the Sierra Nevada, there was a great earthquake in 1872, which only the scantiness of the population prevented from being a great disaster. This quake was accompanied by the formation of a fault of 40 miles in length and having a vertical displacement varying from 5 to 20 feet in height. In the Sonora earthquake of 1887, a zigzag fault 35 miles long and with maximum vertical displacement of 20 feet, was formed in Mexico and Arizona. The Japanese earthquake of 1891 was accompanied by the formation of a fault with elevations of 20 feet or more. In the Great Indian, or Assam, earthquake of 1897 several large faults were formed, from which lesser ones ramify. In the earthquake of 1899 the region of Yakutat Bay, in Alaska, was greatly disturbed, with an elevation of the coast at one point of 47 feet. "The change of level was differential, indicating a complex system of faulting on a large scale." (Tarr and Martin.)

Earthquake displacements may be horizontal as well as vertical, but these are less obvious and therefore less frequently observed. Lateral displacements along the fault scarps, amounting to as much as 20 feet, were a very marked feature of the San Francisco earthquake of 1906, and similar horizontal displacements or "offsets" were observed after the Sumatran earthquake of 1892, the Japanese of 1891, the Owen's Valley of 1872, and the Great Indian of 1897. The latter showed other evidence of horizontal movement and compression, railroad tracks being so squeezed along the direction of their length, that they became regularly serpentine and meandering in their course.

Very common results of earthquakes are changes in the drainage system, both on the surface and underground. The changes in the form of the land surface produce corresponding alterations in the courses of the streams; rivers are diverted into new channels or dammed into lakes, while streams intersected by fault scarps will form new cascades, which will be very short-lived if the scarp is made up only of soil, but will be lasting if it is composed of hard rock. The Indian earthquake of 1897 resulted in the formation of many new lakes.

Violent earthquakes, which have shaken great areas of country, are almost always followed by a succession of *after-shocks*, which may continue for weeks, months, or even years. These after-shocks may be very violent, though they are never so much so as the primary shock, and they gradually die away, until equilibrium is established.

When earthquakes originate beneath the sea, additional complications are met with. If the actual movement in the sea bed be small, and the disturbance be transmitted entirely by elastic waves through the rocks and the sea, the water may not be greatly agitated and ships may encounter earthquakes of this description and seem to have struck a reef or a shoal. This is uniformly the account given by seamen of their sensations under such circumstances. If, on the contrary, any considerable area of the sea bottom is temporarily raised or



RESULT OF AN EARTHQUAKE

Dislocation of a straight railroad track near Rangapara by the Great Indian Earthquake of 1897. (*After Oldham.*)

lowered, great waves are generated which, though hardly noticeable in the open sea and in deep water, pile up on the coast to terrific heights and sweep far inland, often doing more damage and taking a greater toll of lives than the most violent disturbance on land. These waves are often called "tidal waves," but that is altogether a mistake, for they have no connection with the tides—"great sea waves" is a better name for them. The first indication of a great sea wave is the lowering of the water along the coast, and then there rolls in the gigantic breaker which overwhelms all the low-lying lands until it meets hills or plateaus too high for it to cover. The coast of Japan and the west coast of South America have frequently been devastated by these waves; in the Peruvian earthquake of 1868, the U. S. gunboat *Wateree,* which was at anchor in the harbor of Arica, was carried inland for a distance of three miles and left stranded.

The *Causes of Earthquakes* are better understood (at least, we so flatter ourselves) than those of other subterranean operations and, among students of the subject, there is more general agreement than is usually true in dealing with such obscure problems. The new science of earthquakes (*Seismology*) was developed in Japan by the English professors at the University of Tokio, with the highly efficient help of their Japanese students, some of whom later became very high authorities in the new science. As Japan is the country in which earthquakes are most frequent, it was the most favorable place in which to begin such studies; new instruments, of extraordinary delicacy, were invented, to record and analyze the movements of every earthquake and, by an international agreement, similar instruments were set up in special observatories, scattered over all civilized countries, and thus the most distant earthquakes, if violent, are recorded.

From the standpoint of causation, earthquakes are divisible into two classes, the volcanic and the dislocation (or tectonic), but it is not always easy, or even practicable, to make sure to which one of the two classes a given earthquake should be referred.

Volcanic Earthquakes are those which are produced by the explosions of steam and other gases and vapors within a volcano. Quakes of this class nearly always precede the eruption of a vent that has long been dormant, and increase in violence up to the time of the outbreak, when they come to a more or less sudden stop. The first warning that Vesuvius was beginning to awaken was the series of earthquakes which began in 63 A.D. and damaged so severely the Campanian towns, especially Pompeii. The Central American and West Indian eruptions of 1902 were heralded by earthquakes, some very violent, especially those which were caused by the volcano of Santa Maria in Guatemala, a vent which had not been known to erupt since the settlement of the country by Europeans. The frightful eruptions of La Soufrière in St. Vincent, and of Mont Pelèe in Martinique, in 1902, were heralded by numerous and violent earthquakes, which ceased when the eruptions began. In their typical manifestations, volcanic quakes have a definite center of origin, which is in or near a volcano, and are rarely felt over any very extensive area, because, however violent they may be at the point of origin, they diminish rapidly in intensity and, when the shaken area is mapped, it has a roughly rounded outline, no one diameter greatly exceeding the others. The earthquake of 1883 on the island of Ischia was of terrible violence, completely destroying the town of Casamicciola, yet at Naples, only twenty-two miles away, the shock was hardly felt at all.

By far the greater number of earthquakes are referred to the *dislocation* class, which must, of course, include the disturbances which, like those of southwestern and central Asia, northern India, etc., are far removed from volcanic regions. They are due to the sudden yielding of the rocks to the steadily increasing stresses which are generated within the earth and continue to increase until the rocks give way with a sudden jar, which sets up a series of elastic waves, the cropping out of which at the surface produces the sensible phenomena. We are now in a position to understand why very violent earthquakes are so generally associated with faults, which are fractures and dislocations of the rocks; and this explains why the earthquakes of a given nonvolcanic region, when accurately mapped, are seen to proceed from movements along a fault plane, old or new, because a fault, once established, may continue for thousands of years to be a place of oft-repeated movement.

Dislocation quakes are markedly linear, extending, it may be, for hundreds of miles in one direction, and for very much shorter distances in directions transverse to this line, so that the area involved, when mapped, forms a long, narrow strip or belt. In such an instance there has been movement along the plane of dislocation, and from two or more points on that plane waves have radiated, but they soon die away in directions transverse to the line of dislocation. In some earthquakes the disturbance emanates, not from a single plane or dislocation, but from the movements of a fault block, inclosed between several planes. The Indian earthquake of 1897 is referred to the movement of such a block, or, it may be, a series of blocks, having a surface area of 6,000 square miles. Several modern earthquakes which have been carefully studied have clearly pointed to their origin from dislocation of the rocks. The San Francisco earthquake of 1906 was due to renewed movement along the San Andreas fault, one of a series that runs for several hundred miles near the coast and slightly west of north in direction, so that north of San Francisco the faults pass out into the bed of the sea, and reports from ships that have felt the shocks and carefully recorded their position, have made it possible to map the course of the faults along the sea bottom and to ascertain that they are prolongations of the lines of fault on land. The earthquake which shook the island of Jamaica in January, 1907, and largely destroyed the city of Kingston, arose in a submarine dislocation, having an east-west trend, a few miles south of Kingston.

One of the most terrible catastrophes of modern times was the earthquake of December 1908, which reduced Messina, in Sicily, to a rubbish heap and wrecked Reggio, on the mainland of Italy and on the opposite side of the straits. The loss of life was officially reported as 77,283. A narrow belt of habitual shocks runs in a curved line, describing nearly a semicircle, through southern Italy and across Sicily, and the Messina earthquake would appear to have originated in the part of this belt which runs under the straits between Italy and Sicily, as sea waves were thrown on both shores. In Japan the records show that most of the shocks come from the bed of the sea east of the islands. Here lies the profound trough which contains the Tuscarora Deep, and the very steep landward side of the trough would seem to be a fault and the principal seat of origin of the Japanese earthquakes. It has happened several times and in various seas, among others in the North Atlantic, that all the submarine cables in a given region of the sea were ruptured simultaneously and, when the breaks were marked on a map, it was seen that one straight or simply curved line would connect them all.

Economically considered, earthquakes might seem to be even more completely malign and evil than are volcanoes. But this is not entirely true, for earthquakes are but one expression, a by-product, so to speak, of activities that are essential to the continuation of land life on the earth; the activities, namely, of those movements of the earth's crust which increase the irregularities of the earth's surface and thus cause the elevation of the land. Had there been no movements of land upheaval in the past ages of the earth's history, the denuding agents would long ago have swept away the land and left only the universal sea.

In the second place, there is every reason to hope that the great destruction of life and property, which has so long been allowed to devastate some of the most delightful countries, may in the future be avoided. Anyone who reads with care the accounts of the most destructive and desolating earthquakes cannot fail to note that by far the greatest loss of life takes place in the cities and through the collapse of buildings and the inundations of great sea waves; in the open country but few people are killed, and the damage to property is comparatively small, except on low sea coasts. Enough has already been learned to make building methods quite safe and even earthquake-proof; and it is an unwise conservatism, a thoughtless adherence to old and discredited ways, which has been responsible for some of the worst holocausts of modern times.

Thanks to the instruments which are used in recording and measuring earthquake shocks, the engineer and builder are now dealing with known and measurable forces which, it must ever be remembered, are applied chiefly in a horizontal direction; it is this direction which makes them so dangerous to ordinary structures, which are designed to resist vertical stresses. It is now possible to determine the height to which a wall may be built to resist a given shock to its foundation. It is at the base of a structure that yielding and failure begin, and therefore the lower part of the structure must be the strongest. Piers for railway bridges in Japan are given extra large dimensions at the base and taper upward, so that each level has the strength known to be necessary to resist the horizontal forces. The cast iron, cylindrical piers, which once were quite extensively used, were long ago abandoned as being entirely inadequate to the requirements of earthquake conditions. Arches of brick or stone, or arched openings in walls, heavy gables, cornices or chimney caps, have all proved to be sources of weakness and hence are to be avoided. Building sites on soft ground or "made land" are dangerous, because in such places the movement is always greater than in hard ground or rock. The sides of openings that are not especially supported, such as river banks, bluffs, railroad cuttings, should be shunned, because there is always an extreme degree of movement on unsupported faces. In buildings, it is important that the roof be made as light as possible and the roof frame be anchored firmly to the walls and floors below, and that, in general, no joints be left free, where the structure can be torn apart, such as corners and the junction of internal partitions with the floors and the outer walls. The experience of San Francisco was that reenforced concrete on solid ground was one of the most satisfactory modes of construction, for a properly designed and well-constructed concrete building is practically a single piece, a monolith, and moves all together, as one block. Somewhat unexpectedly the steel frame, or "skyscraper," especially in those buildings in which the foundations were carried down to rock, proved itself to be an excellent method of construction. The elasticity of the steel frame caused it to sway and yield to the horizontal movements of the ground without rupture.

The second source of danger to human life in earthquake lands is in the great sea waves which are generated by submarine volcanic eruptions, or, much more frequently, by earthquakes that originate in the bed of the sea. Very often these great waves, which rush in over the land as gigantic breakers, take a heavy toll of lives.

CHAPTER XIII

CLIMATE.

ONE of the most important factors in determining human welfare is climate. It is true, man has adapted himself to all climates, and has so spread over the globe that no large land mass, except the Antarctic continent, is devoid of human inhabitants; but civilization arose and has maintained itself only in the north temperate zone, except as it has been carried to other regions by colonists from that zone. Whether the white race can ever so adapt itself to the tropical climate as to thrive in it, or can so change conditions as to make the tropics suitable for European settlement, must be left to the future to decide; so far, only small areas, like the Panama Canal Zone, have been made suitable, and that at a prohibitory expense. Civilization cannot exist on any large scale in the polar lands, for there agriculture cannot be carried on and only a scanty population can be supported by hunting and fishing; even the pastoral nomadic life is impossible. No geographical factor has had so profound an influence upon history and culture as has climate.

The elements which enter into climate are temperature, moisture and prevailing winds and storms. Temperature is, of course, dependent on the sun and, where other things are equal, varies according to latitude, diminishing from the equatorial, or torrid, zone to the poles. But other things are so seldom equal, that places on the same parallel of latitude may, and very frequently do, have very different temperatures. Many people have been puzzled to account for the fact that countries in the same latitudes, but on opposite sides of the Atlantic Ocean, should have such very different climates. The south coast of England is one of the mildest and most genial regions in the temperate zone, and plants grow there which are found nowhere else north of the Mediterranean shores. Yet, when the latitude of the southern English coast is traced across the Atlantic, it is found to cut through Labrador, a most inhospitable region of short summers and long, intensely cold winters. The north of Scotland and much of Norway are in the latitude of Greenland, most of which is buried under a perpetual mantle of ice.

Contrasting the temperatures of points on the Atlantic and Pacific coasts of North America which have the same latitude, we find the same sort of difference. San Francisco is on nearly the same parallel of latitude as New York, but knows almost nothing of ice and snow. Sitka, in Alaska, has milder winters than New York, though Sitka is so very much farther north. Between the two shores of the Pacific there is the same contrast, the climate of eastern Asia being very similar to that of eastern North America in corresponding latitudes.

Evidently, in all these cases, some other factor than latitude enters into the determination of temperature, and that factor is the one of prevailing winds. In the temperate zones of both the northern and southern hemispheres the prevailing winds are westerly, blowing from some westerly quarter more than three-fourths of the time. On the east side of a continent, therefore, the prevailing winds blow from the land, while on the western side of the same continent they come off the sea. In summer time the land is heated to a much higher degree than the sea, even though the amount of heat received from the sun on equal areas of the land and the sea should be identical. Likewise, in winter the land becomes chilled to a much lower temperature than does the sea; hence, in winter, land winds are cold, and in summer they are hot; while winds from the sea have a much smaller range of temperature, being cooler in summer and warmer in winter than those which blow over the land. This explains why the eastern side of a continent (or, what amounts to the same thing, the western shore of an ocean) has a climate of extremes, called a "continental climate," in which there is very great annual range. In New York there may be a range of 120 degrees F. in the course of a single year.

In the southern hemisphere there is no such difference between the two sides of a continent, because the south temperate zone contains relatively so little land and such vast expanses of sea, that the climates are practically insular throughout, especially as no continent, except the Antarctic, extends to a high southern latitude.

The difference between the two shores of the Atlantic is often stated to be equivalent to ten degrees of latitude, which is to say, that points in western Europe have about the same climate as those which are ten degrees farther south on the American side. This statement is, however, somewhat misleading because the extreme fluctuations of temperature, which are usual in eastern North America, occur but rarely in western Europe. The summers, as a rule, are cooler and the winters milder there, and the annual range of temperature is therefore notably less. The climate of western Europe is "insular," like that of an island, in which the principal influence comes from the sea. Passing eastward across Europe, the influence of the sea gradually diminishes and the climate becomes continental, with wide annual range. The winters in Russia are much longer and more severe than they are in corresponding latitudes of France or even of Germany.

Since the winds are so important a climatic factor, it is necessary to say something of atmospheric circulation, which is due to the heat of the sun, for it is differences of temperature and consequent atmospheric pressure that cause atmospheric circulation. The whole system of winds swings north and south, following the apparent path of the sun in its passage north to the Tropic of Cancer and then south to that of Capricorn. The effective Equator of the wind system coincides with the geographical Equator for part of the year, moving north of the latter in the northern hemisphere summer, and south of it in the southern hemisphere summer; it is sometimes called the "heat equator," because it is the belt of highest temperature. The shifting of the heat equator and, with it, of the system of winds, lags behind the sun's migration, and does not reach its northernmost point on June 21st, the summer solstice, when the sun is farthest north, but in September. It is the same with the daily range of temperature; the hottest part of the day is not at noon, when the greatest amount of heat is coming from the sun, but at 3.00 P. M. The equatorial belt is a zone of calms, which sailors call "the doldrums," it is a belt of low barometric pressure, of ascending air currents, and almost daily rains and thunderstorms. The air currents which rise in the equatorial belt, flow off, both northward and southward, toward the poles, gradually descending as they go. On both sides of the equatorial belt are the trade winds, which are blowing from the tropical belts of high pressure to the equatorial belt of low pressure, that being the invariable law of the winds, for there must be an inflow of air to take the place of the air which is rising in the equatorial zone. If the earth did not rotate on its axis, these winds would be northerly winds in the northern hemisphere, southerly winds in the southern, but the rotation of the earth deflects them. We have already learned, in connection with ocean currents, that in the northern hemisphere a body moving in any direction is deflected to the right, and in the southern hemisphere to the left. Winds are affected by the earth's rotation in the same way as are other bodies, and so the trade winds of the northern hemisphere become the "northeast trades," and those of the southern hemisphere the "southeast trades." The trade winds blow over the sea with astonishing steadiness and regularity, but they are only about two miles in depth; above them are the "antitrades," which are westerly, and mountains that rise more than 10,000 feet above sea level feel the antitrades on their summits. In summer the northeast trades migrate northward so far that the Mediterranean lands and southern California are included in their regions, with very marked effect upon the climate of these countries.

Poleward from the trade wind areas are the tropical belts of high pressure, which are somewhat vague in extent and, in sailor's phrase, are the "horse latitudes." Like the doldrums, they are belts of calm and light, baffling winds, but differ notably from the equatorial belt in having prevailingly bright, clear weather, with little rain. The doldrums, or equatorial belt, are an area of low barometric pressure and ascending currents of air; the horse latitudes, on the contrary, are belts of high pressure and descending air currents. Outside again of the horse latitudes in each hemisphere is the region of westerly winds which covers the temperate zone and extends into the frigid zone. In this great mass of easterly moving air there is a continual procession of eddies and whirls; some of these are areas of low pressure, into which the winds blow spirally from all sides; others are areas of high pressure, from which the winds blow spirally outward. The areas of low pressure are cyclones, and those of high pressure are anticyclones. The term cyclone is often, but incorrectly, used for those violent and fearfuly destructive local storms which should be called tornadoes.

The weather changes of the temperate zone are controlled by this unending eastward procession of cyclones and anticyclones. When the storm center of a cyclone is approaching a given point from the west, an observer at that point notes that the wind is blowing from the northeast, which usually brings rain. If the storm center passes to the north of the observer, the wind veers to the southeast, south and southwest, and west, which brings clearing and warmer weather, while if the center passes to the south of him, the wind backs into the north and northwest which, especially in winter, brings clearing and much colder weather. Like all the other elements of the wind system, the track which is followed by the procession of cyclones and anticyclones shifts according to the apparent path of the sun, moving northward in summer and southward in winter, but the position of the track is not fixed and invariable for a given season, but fluctuates within limits, for unexplained reasons. If the storm track in winter passes to the north of a given locality, that place will have prevailingly southerly or southwesterly winds and, in consequence, a mild winter, but if the track is to the south of the place, the prevailing winds will be northerly and northwesterly, and the winter will be a severe one. In the same way, the position of the cyclone track will determine whether the summer shall be very hot or moderately cool for a given locality. It is the eastward march of the cyclonic and anticyclonic centers which has given rise to the popular and correct aphorism that "the weather comes from the west."

The monsoons are remarkable winds, best seen in the Indian Ocean, which is cut off by the westward extension of Asia; they might almost be defined as land and sea breezes on a gigantic scale. In summer, when the land is highly heated, it heats the air in contact with it, and the expanded warm air rises; to take its place air pours in from the sea, and the winds thus generated cover the whole northern part of the Indian Ocean from Africa eastward. These make the southwest monsoon, which brings the vitally important summer rains to India. In the winter, conditions are reversed; the sea is warmer than the land and the area of low barometer is over the sea, so that the winds blow outward from the land, forming the northeast monsoon. It was by taking advantage of the southwest monsoon that Vasco da Gama was able to make his memorable voyage in 1498 from the east coast of Africa to Calcutta, in India.

The system of winds which has been sketched in outline in the foregoing paragraphs, is most definitely marked over the sea, because of the sea's uniformity of conditions. On land there are a great many local conditions, which modify and obscure the systematic winds. Mountain ranges deflect winds, often forcing them far out of their normal course; areas of unusual heat or cold, high or low barometer, may generate winds which have no evident connection with the general system of atmospheric circulation. Nevertheless, that system does dominate the winds of the earth. At very high levels the current is everywhere eastward except for a westward current at the Equator, and is obviously produced by the earth's rotation.

The second great factor in determining climate is moisture, which is usually expressed in terms of rainfall, and snow is expressed in the same terms, what would be the amount of it, if melted, for snow is much more voluminous than the same weight of rain. As a general term to include snow, rain, dew, condensed fog, in short, all the water which is condensed from the atmosphere and reaches the ground, *precipitation* is often employed, but rainfall may be used in the same sense. It is not sufficient to know what the annual rainfall of any given region may be, because regions in which the annual precipitation is the same, may yet differ very greatly in regard to moisture. It is necessary to ascertain how the rainfall is distributed throughout the year; whether, as in the tropics, there are definite dry and rainy seasons, or whether, as in India, there are particular rainy seasons, or whether, as in western Europe, the rain is distributed throughout the year, though with more in the autumn and winter than in the spring and summer. The precipitation of the northeastern United States is rather greater in total than that in most parts of England, but with the very great difference that in England the number of rainy days is much greater, the precipitation being much more frequent but also more gentle, the torrential downpours that we so often have being quite uncommon in Great Britain. The extraordinary verdure of England, and the even more remarkable and proverbial green of Ireland, the "Emerald Isle," are due to the manner in which the rainfall is distributed. With a rainfall as great, or greater, we have the drier climate. Especially important for the agriculture of any country is it to know whether the rains continue through the summer, or whether they are confined to the winter and early spring.

The moisture of any body of air is not an absolute, but a relative, quantity, dependent upon the temperature of the air, for the capacity of the air for moisture increases as the temperature rises. So long as the air is cold, the increase in the capacity to take up moisture as the temperature rises is very slow, becoming very much more rapid when the air is really warm. When the temperature of a cubic foot of air is raised from thirty degrees to forty degrees, its capacity for moisture is increased by .89 of a grain, while if the increment be from eighty degrees to ninety degrees, the increased amount of water vapor which can be taken up is 3.86 grains. In both cases the actual rise of temperature is ten degrees, but the increase from eighty degrees to ninety degrees causes the absorption of four times as much water as the rise from thirty degrees to forty degrees. A given volume of air might have the same amount of water vapor at forty degrees as when heated to 100 degrees, yet the cold air would be moist and the hot air dry, with exactly the same moisture content. What, then, is meant by the terms, dry air and moist air? Moist air is saturated with the water vapor which it can take up at its temperature, and is ready to deposit water by condensation, while dry air is far from saturation and will take up much more water vapor. The actual amount of moisture is thus less significant than the relative quantity. The distinction between actual and relative moisture explains why our steam-heated and furnace-heated houses are so excessively dry in winter time. The cold outside air is taken into the furnace, or into the house, and highly heated, so that its capacity for moisture is greatly increased, but the moisture is not properly or effectively supplied, with the result that, in winter, the air in the average American house is dryer than in any desert on earth. A properly designed system of heating would supply the needed moisture and thus effect a great economy of fuel, for in air with proper moisture content it is possible to be comfortable at a much lower temperature than when the air is unduly dry.

The term *humidity* is applied to express the quantity of moisture in the air, and in the daily weather reports which the newspapers publish, it is the relative humidity that is given. When the report reads, "humidity 75," that means that the air contains three-fourths of the water which it can absorb at that temperature. A rise in temperature without a corresponding increase in the actual amount of water would decrease the humidity, as a fall in temperature would increase it. When heat and humidity are both very high, as they so often are in August, the weather is very oppressive, for the almost saturated air does not permit the rapid evaporation of perspiration, which cools the skin in dry air. A temperature of 110 degrees in the arid West is much less oppressive than 90 degrees in the humid East, as the writer can testify.

The density of the atmosphere diminishes upward, because the lower layers are compressed by the weight of the air above them. Hence, an ascending column of air is steadily expanding as it rises, and expansion cools it, so that its relative humidity increases and, a little below the saturation point, begins to form clouds by condensation of its water vapor. A descending column of air, on the contrary, is being compressed, and compression raises its temperature, increasing its capacity for moisture. Ascending air is moist, descending air dry, a principle which is most important in attempting to understand rainfall. Two air columns, one ascending, the other descending, may have the same actual humidity, yet the ascending air is moist and the descending air is dry.

This explains the rôle which high mountain ranges play in regard to rainfall. When lofty ranges cross the course of moisture-laden winds blowing in from the sea, they force the wind to ascend, thus expanding and cooling the air and reducing its capacity for moisture. Part of the contained vapor condenses and falls as rain or snow, giving a heavy precipitation on the windward and seaward side of the mountains. After the wind has passed the highest crest of the mountains and begins to descend on the landward side, it is being compressed and grows warm and dry; it is dry, not only because it has been robbed of part of its moisture, but because its rising temperature increases its capacity for moisture. The contrast in the amount of precipitation on the two sides of the Cascade Mountains, or the Sierra Nevada, or the Himalayas, is most striking. On one side is moisture in excess, enormous masses of snow, or tremendous downpours of rain, and on the other side is aridity. The plains and most of the plateaus to the eastward of the Sierra Nevada and the Cascades are desert or semiarid; north of the Himalayas is the dry, cold table-land of Tibet, and north of that the desert basins of central Asia. The Alps have no such influence, because rain-bearing winds come in from the Atlantic and from the North Sea, extending their influence even into Russia, though in that country, east of Poland, the rainfall is hardly more than half of that in western Europe.

The winds that blow over the surface of the sea become laden with moisture and carry it inland for the rains of the land surface. Hence, when any part of the land is cut off from the sea winds by high mountains, that area is dry. The trade winds are dry, partly because they are derived from descending currents and partly because they blow from cooler to warmer latitudes and their rising temperature steadily increases their capacity for moisture. Consequently, these belts are everywhere marked on land by deserts, which encircle the earth. Yet, when the trades are forced by mountains to ascend, they become rainy winds. The Hawaiian Islands lie in the track of the northeast trades, which blow from March to December; on the windward side of the mountains precipitation is very heavy, but on the leeward side there is great lack of rain.

The problem of the white race in the tropics is partly, perhaps chiefly, a problem of disease. Some tropical diseases which are fatal to white men are borne with comparative immunity by various colored races, but others are not. The Chinese thrive in the tropics, as do the Malays of the East Indies, the Negroes of Africa, and the Indians of Brazil and Venezuela, but these are cases of adaptation, or acclimatization, which may have taken many centuries to accomplish. Whether the white man can ever accomplish this remains to be seen; so far, he has not succeeded.

Remarkable progress has been made in the control of tropical diseases, notably of malaria and yellow fever, as has been displayed in the work of the United States Army Medical Corps in Cuba and in the Isthmus of Panama, and by the surgeons of the British Army on the Suez Canal. Even so, however, this control is but a partial and imperfect one. The methods of sanitation are very costly and require a rigor of administration such as most people will not endure. Only a very small proportion of the Panama Canal Zone has been subjected to minute sanitary control, and yet that required the expenditure of half a million dollars annually, not including the cost of hospitals, medical supplies, doctors and nurses, but merely the *preventive* measures. As against yellow fever success has been complete, and no case of this disease has originated on the Isthmus since 1905, but even eternal vigilance has not entirely availed against malaria.

Even aside from specific diseases, the tropics have a deleterious effect upon many white men.

Even when all other conditions are favorable to the health of the white race in the tropics, the unchanging monotony of the climate is a drawback to efficiency, for observation and experiment have shown that seasonal changes and frequent cyclonic storms promote the well-being of the white man. Altitude largely diminishes the ill effects of the tropical sun, as, for example, on the high plateaus of south-central Africa, but altitude does not diminish the effect of the intense tropical light, nor does it give the variety of weather which white men seem to need.

It is commonly supposed that the natives of tropical countries are immune to the tropical diseases which are so deadly to the white man. This appears to be true in a large measure of yellow fever, but not of sleeping sickness, bubonic plague, malaria, or hookworm. Almost all dwellers in the tropics suffer from malaria, though in latent, rather than active form, and the inertia and apathy observed among so many tropical races is largely due to this malarial infection. Undoubtedly, malaria is the greatest obstacle to human health and happiness that is to be found in the tropics.

The civilization of the ancient world was confined to the warm temperate zone. This, of course, leaves China out of account, but China has had but little influence upon the development of the West, because of the way in which that empire secluded itself and refused to have dealings with foreigners.

The civilization which meets us at the beginning of recorded human history is centered around the Mediterranean, gradually spreading along the coasts of that great inland sea from east to west. Egypt and Crete, Assyria, Babylonia, the Phœnicians, the Lydians, the Persians, the Greeks, Carthaginians and Romans were all Mediterranean powers and were settled either directly upon the coasts or were within the influence of that sea, the "Great Sea," as it is called in the Bible. Until the barbarian invasions overthrew the Western Empire and the modern European nations had their faintly marked beginnings, history has little to tell us of the world outside of the Mediterranean lands. The Mediterranean type of climate is found in California, at the Cape of Good Hope, in parts of Chile, and in southern and southwestern Australia, where similar conditions recur.

The Mediterranean lands are alternately affected by two great wind systems, as these shift northward and southward, following the course of the sun. In summer these lands are brought within the influence of the trade winds, which are dry, and consequently the summer rains are scanty, and in the southern portion of the three Mediterranean peninsulas, Spain, Italy, and Greece, there is almost no rain in summer. In winter the trade wind belt shifts southward, and its place is taken by the rain-bringing southwesterlies, but even the winter rains are not copious, and in the interior of the larger land masses, such as Spain and Asia Minor, they are scanty.

Another feature of the Mediterranean climate is its warmth, which is not excessive; the summers are cooler than in corresponding latitudes in Asia, which is due to the moderating effect of the sea itself, and the winters are very mild, for the same reason. Killing frosts are rare and so agriculture, where water for irrigation can be obtained, is highly favored, and life for many of the ancient nations was very easy. The taming and eventual civilization of Europe north of the Alps were far more laborious tasks, and it is easy to see why France should have long held the lead in this work. Not only was the conquest of Gaul by the Romans followed by an extensive civilizing work, but France was a Mediterranean, as well as a western European, land, with its southern regions belonging to ancient civilization. By situation and history France was fitted to be the mediator between the old civilization of the Mediterranean lands and the newer civilization of western and northern Europe.

Europe north of the Alps is a region of rains distributed throughout the year, but greater in winter and diminishing in amount eastward, as the influence of the sea gradually dies away. It is also a region of killing frosts, so that winter is a season of dormant vegetation, but the winters are mild in the west, growing more and more severe eastward. In these countries agriculture can be carried on without irrigation, the rainfall being sufficient for all needs.

The monsoon countries of southern and southeastern Asia differ in climate from the Mediterranean countries chiefly in having summer rains, which is a feature more favorable to agriculture, for summer is the season of rapid plant growth. Hence, as might be expected, these monsoon countries are very densely peopled, so that the population presses hard upon the food supply. When the monsoon does not "break" and the rains fail to come, as sometimes happens, terrible famines sweep away multitudes in those overcrowded lands.

Much the greater part of North America lies in the track of the prevailing westerly winds, and yet the abundant rainfall of most of the continent is derived, not from the Pacific, but from the Atlantic and the Gulf of Mexico, because the Pacific winds are robbed of their moisture and converted into drying winds by the high mountain ranges which run parallel to the coast and not far inland. These mountains cast a "rain shadow" a long way eastward, and are bordered by a broad belt of deficient rainfall, desert in the south, semiarid in the north. Over the remainder of the United States and Canada the rainfall is due to the cyclonic storms, which draw in moisture-laden winds from the Atlantic and the Gulf. In the upper Mississippi Valley the summer precipitation exceeds that of the winter, which is largely brought about by the frequent thunderstorms. The Gulf of Mexico is an especially fortunate circumstance for the habitability of North America; had that area been land, it would have lain in the track of the trade-wind deserts of northern Mexico and would have greatly diminished the precipitation over the interior of the continent. "Although droughts sometimes afflict considerable districts, and floods occasionally devastate the larger valleys, yet the world hardly contains so large an area as this so well adapted to civilized occupation." (W. M. Davis.)

Both from the historical and the geographical point of view, it is an extremely important question as to whether there have been any significant changes of climate within the historic period. Accurate weather records have been kept for only a couple of centuries, and in only a few places can they be carried back so far. These records lend no support to the very general belief that climatic changes are now in progress, and therefore most meteorologists are inclined to deny that such changes have taken place within historic times. All are agreed that the earth, in former geological ages, has passed through many fluctuations of climate, which are unmistakably recorded in the rocks.

If the climate of any considerable part of the earth's surface has changed within the last few thousand years, the evidence of the change must be chiefly indirect, and such evidence has, of late years, been strongly presented by the work of Messrs. Pumpelly, Huntingdon, and Penck. So careful and competent a geographer as Professor D. W. Johnson has expressed his agreement with the conclusion, "that the evidence thus far available supports the belief that there have been great climatic changes" within the recent period. It is impossible to exaggerate the importance of this conclusion in rendering intelligible the history of mankind in the last four or five thousand years, and explains much that has hitherto been obscure in its modes of causation. The evidence consists in the results of researches undertaken in central Asia, Persia, Asia Minor and Palestine, and also in central and southern California. The results indicate that a progressive desiccation of the regions named has been going on for many centuries past, as is shown by the very many abandoned cities now given over to the desert, extensive irrigation works where now there is no water, dried up springs, great areas of dead forest, killed by drought, and roads through the desert that once were used by armies, but are now too dry for caravan traffic. The fluctuations of the Dead Sea in Palestine, as recorded by the strand lines and beaches at various levels, also point to a progressive desiccation of that region. The sequoias, or giant trees of California, have preserved a record in their annual rings of growth, that goes back nearly 4,000 years. It has been definitely shown that the varying thickness of the growth rings in the trunks of trees accurately records fluctuations in the rainfall. Professor Huntington measured the thickness of the annual rings in 450 trunks of California sequoias, which gave a fairly accurate climate record for 2,000 years back from the present time, and an approximate record for 1,000 years beyond that. Both the records of the trees and the sequence of events in Asia agree in indicating that the climatic changes did not consist in a simply continuous desiccation, but that there were many fluctuations of moister and drier periods, while the net result of all the fluctuations was a greatly diminished rainfall. The agreement between Asia and California points to the conclusion that the change was world-wide.

From California to China, by way of Europe, there are indications that in the fourteenth century was a time of abnormal storminess and precipitation, but that was merely an episode in the process of desiccation which affected both hemispheres.

The climatic oscillations in Asia, repeated from time to time, not improbably were the causes of the frequent waves of migration and invasion, which for thousands of years poured into Europe from Asia, and almost entirely from central Asia.

CHAPTER XIV

THE VEGETATION OF THE EARTH.

THE term "*flora*" is one that is very widely used, and should be defined at this point; it means the totality of plant life for a particular place or time. Thus, we speak of the flora of Cuba, or the flora of Asia, or the flora of the Cretaceous period in geological time. Flora and vegetation do not have precisely the same meaning; for vegetation refers to the number of individual plants in the region referred to, while flora refers to the number of different species. The flora of a given land may be very rich, consisting of a great number of species, and yet the vegetation of the same land may be sparse, only a few individuals per unit of area. Likewise, a luxuriant vegetation may constitute but a scanty flora, for, though it has countless individual plants, only a few species are represented. The European flora of forest trees is far less rich and varied than that of North America, yet the vegetation composed of those few species is often extremely dense.

The conditions which determine vegetation are, in one word, climate, modified by conditions of soil, for both plants and animals are much more dependent upon climatic conditions than is man, since man has adapted himself to all climates, which none of the higher animals or plants have succeeded in doing. No climate can produce a rich and varied vegetation upon a surface of hard and naked rock, or of drifting sands, though it is often astonishing to see how trees can maintain themselves upon a rocky flat, or even a cliff, sending their roots into every crevice. As the soil changes, even when climatic conditions remain the same, the vegetation changes and, inasmuch as the soil is so generally the product of the decomposition of the underlying rock, it is the underlying rock which, in the last analysis, determines the distribution of plants under similar climatic conditions. Certain trees, bushes, and herbs will not grow upon a clay soil, others will not thrive upon a sandy soil; calcareous, or limy, soils are favorable to some plants, impossible to others; while a fourth group flourishes on soil impregnated with salt, which most plants cannot endure. Then, finally, there are tough and hardy plants that will grow on almost any soil.

There is a very distinct climatic limitation to the distribution of plants. If these limitations are marked on a map, the boundaries of the different vegetable groups are seen to be very irregular, but this very irregularity is determined by climatic factors; the lines of equal temperatures, or "isotherms" are frequently barriers which plants, and animals too, are utterly unable to cross.

Temperature and moisture are the two factors which are most important in determining the distribution of plants, and temperature is, broadly speaking, determined by latitude, though, as was shown in the preceding chapter, the temperature proper to latitude is greatly modified by prevailing winds, by the nearness or remoteness of the sea, by ocean currents, by altitude above sea level, and similar factors. In many respects altitude is equivalent to approximation to the polar regions, because the atmosphere grows colder with increasing height and even in the tropics an elevation of 16,000 or 17,000 feet above the sea brings a mountain peak above the level of perpetual snow. But, despite the lowering of the temperature, there are differences between great altitude and high latitude which are especially important to plants. All green plants demand light; the light of the sun is essential to their physiological processes, especially of nutrition, and the need of light grows more intense as the temperature is lowered. The mountains of temperate, and especially of tropical, latitudes enjoy an abundance of sunlight, while the polar regions have six months of night. It is true that they also have six months of day and that, while the sun is above the horizon, vegetation grows more rapidly because of the continuance of the light. For example, in the far north of Norway, barley is ripe for the reaper within eighty-nine days after sowing, while in the north of Germany it requires over 100 days. There is no doubt that continual sunlight stimulates to more rapid growth, though only after the temperature has risen to the point at which vegetation is awakened from the dormancy of the long Arctic night. Though the total number of hours of sunlight in the course of the year be the same for temperate and polar latitudes, its concentration into a single six months' day, followed by a night of corresponding length, produces very different effects on plant life. The Arctic plants which are found high up in the Alps (a distribution which has nothing to do with the present climatic zones, but is the result of the altogether exceptional conditions which prevailed during the oft-mentioned Glacial Epoch) are larger and of more vigorous growth than the same plants in the Arctic regions. The chief difference between the high Alps, where a polar temperature prevails, and the Arctic regions, is in the amount and intensity of the light and in the length of the day, for these factors are not affected by altitude.

Looked at broadly, we may divide the vegetation of the earth into climatic zones, tropical, warm temperate, cold temperate, and polar; but within these zones there are great differences, largely produced by variations in the supply of moisture, and minor differences occasioned by changes in the soil.

In the tropics there is a most extraordinarily luxuriant vegetation, wherever there is moisture sufficient to support it. In regions of heavy rainfall, such as Brazil and the west coast of equatorial Africa, the tropical forest is at its maximum development, and is an overpowering display of vigor and growth. The tropical forest, in moist climates, is characterized, first, by the extraordinary number of species represented, which much exceeds the number found in higher latitudes. In fact, the number of different species, both of plants and of animals, diminishes from the equator poleward. Tropical forests rarely consist of large numbers of a single species of trees, though they sometimes do in certain exceptional cases. In the temperate zone, on the contrary, we are accustomed to forests in which some one tree, or group of trees, predominates; thus we have forests of pine, forests of spruce, of fir, or hemlock, or forests of oak or beech. In the tropics one may find some striking tree, and then spend half a day in search before finding another specimen of it.

In tropical forests the struggle for existence is so intense (one may call it fierce without exaggeration) that the forest may be described as being arranged in a series of layers. First, there are the tall trees, 200 feet or more in height, with their leafy crowns exposed to the full and unobstructed light of the sun. At a lower level are the tops of the smaller trees, 100 feet or so above the ground; the diffused light which makes its way through the tops of the higher trees is so intense that it suffices for the necessities of the smaller trees. A third layer is formed by the bushes and shrubs, and a fourth by the herbs and plants of herbaceous habit, which grow close to the ground. The tropics do not have many of the kind of plants which gardeners call "annuals," plants, that is, which bloom, mature their seed, and then die, and must be freshly grown from seed every year. Most of the plants grown in our vegetable and flower gardens are annuals. This habit of growth is an adaptation to a climate in which the winters are so severe as to arrest growth by killing frosts. The seeds survive the winter, and are ready to germinate in the following spring. In a climate which has no winter and in which growth continues throughout the year, the annual habit offers no particular advantage. By this arrangement in layers, a maximum number of plants can obtain the amount of light which is indispensable for the physiological processes of growth and nutrition. To a green plant, and green plants form an overwhelming majority of the vegetable kingdom, light is as necessary as water; and in the dense tropical forest the struggle for existence is, in large measure, a struggle for light.

A second characteristic of the tropical forest is the abundance of palms, a group of which a great many different species are known. Palms grow in all the tropical lands of the earth, even in the most distant oceanic islands, and they extend beyond the tropics into the warm temperate zones.

In the third place, when there is sufficient moisture, the tropical forests are characterized by the bananas and their allies, which have fleshy trunks, exceedingly large and soft leaves, and great bunches of fruit, a yard or more in length.

Fourthly, the immense number of climbing plants is very characteristic of the tropical forest, and they grow in loops and festoons from tree to tree, often to inordinate lengths. The rattan is such a plant, belonging to the palm family; in fact, it is a climbing, trailing palm, and grows abundantly in the East Indies. These climbing and trailing plants add immensely to the impenetrability of the forest, in which the traveler has painfully to cut his way at every step. Finally, may be mentioned the great number of epiphytic plants, more or less parasitic in habit, which grow upon trees. Some of these embrace and finally kill the tree upon which they fix themselves, others merely utilize the tree to get a place of less overcrowded growth. Great numbers of ferns grow in this fashion and most orchids, a family which is enormously represented in the tropics and which, in variety and beauty of flowers, is one of the most remarkable of existing plant groups.

The west coast of equatorial Africa has a heavy forest, very much like that of Brazil; and this "rain forest," as it is called, extends eastward upon the interior plateau and near the great lakes of the Rift Valley. There the character of the vegetation changes, because of the diminished rainfall. Southern Asia and the great islands of the East Indies, or Malay Archipelago, including New Guinea, have luxuriant tropical growths of the rain-forest type, which thus, with relatively short interruptions, encircle the earth, so far as land areas are concerned. Much of the interior plateau of Africa which lies within the tropics has a very severe dry season, and here the forest becomes totally different from the dense and luxuriant rain forest of the west. The trees are greatly reduced in number and in size, often degenerating into scrub; there are but few palms and little underbrush. In the dry season most of the trees shed their leaves, and then the forest assumes the appearance of a temperate zone forest in winter. In both cases it is the lack of water which forces the trees to a dormant state of hibernation, and the leaves are got rid of because they are the organs by which the evaporation of water into the air is carried on.

The two strongly contrasting types of tropical forest may be seen side by side at the Victoria Falls of the Zambezi, in Rhodesia. There the upland, through which the river has cut its gorge, is covered with open, scrublike and scanty forest, in which there are no large trees, but few palms, and very little undergrowth. In the dry season, which comes in the winter of the southern hemisphere, the trees lose their leaves, and nothing can be imagined which is less suggestive of the tropics than such a landscape. On the cliff facing the great main fall, across the narrow chasm into which the river plunges, the air is constantly filled with spray and the ground is always wet. Palm Kloof, on the other side of the

Zambezi, is a narrow ravine, which leads down from the table-land to the water's edge below the falls. On the spray-soaked ground above and in the depths of Palm Kloof, the conditions of the rainy tropics are reproduced, and a luxuriant growth of tropical vegetation is the result. The contrast between these little jungles—for they are quite small—and the open, scrubby forest of the table-land is most striking, especially in the dry season, when the winter landscape is suddenly exchanged for the hothouse atmosphere of the jungle.

High mountains in the tropics display all the zones of vegetation that are passed through in going from the equator to the poles; at the base is tropical forest, followed in ascending order by warm and cold temperate forests, ending at a definite level in dwarf trees at "timber line." Above the limit of trees, a few individual trees may be found in sheltered and otherwise favored spots, but the vegetation consists chiefly of grass and herbaceous plants and, still higher, only naked rock, ice, and snow are to be seen.

The warm temperate zone is characterized by certain deciduous trees, which are evergreen, retaining their leaves throughout the year, such as the live oaks of California and the Southern States. At Cape Town, South Africa, one may see in winter the new oak leaves replacing the old ones as they fall. Of course, in the warm temperate area, many trees lose their leaves in winter, frost and snow being occasional visitors in such latitudes, except in islands where the tempering effect of the sea is in operation. Frosts occur in Florida, almost to the southern end of the peninsula, but in the Bermudas, which lie considerably farther north in the latitude of North Carolina, frosts are unknown; they lie full in the track of the Gulf Stream and have a mild and nearly uniform climate through the year. On sandy and other poor soils, even in the warmer parts of the temperate zones, pines and other coniferous trees take the place of the deciduous kinds, which need a generous soil in which to thrive, and certain trees are bound to certain kinds of soil.

In the cold temperate zone of the northern hemisphere the forests gradually pass from hardwood and other deciduous trees to coniferous trees, pines, spruces, firs, and the like. A broad belt of coniferous forest crosses North America obliquely, from Alaska southeastward to Labrador, originally covering all of southern Canada and extending much farther north on the Pacific than on the Atlantic coast. The northern edge of this forest belt is the poleward limit of trees, and beyond it lie the open Arctic plains and the frozen tundra of the Barren Grounds. In the southern hemisphere, on the west coast of South America, evergreen forests of deciduous trees extend into high latitudes of the cold temperate zone. In southern Chile and Tierra del Fuego the Pacific coast is very rainy and, because of the small area of land and very wide expanse of sea, the climate is equable and, though never warm, it is never very cold. The forest is composed principally of a single species of tree, a beech. Such conditions are not repeated in high latitudes of the northern hemisphere.

Within the temperate zone is found a great variety of "plant formations," as botanists call them; that is, associations of different kinds of plants that grow in the same area, and these associations are determined by climate and soil.

Swamps, which are always wet, river flood plains, which are periodically overflowed, dry hills, high mountains and plateaus, all present different assemblages of plants, even when there is no great difference of climate. For moisture, in particular, is a question of storage in the soil and subsoil, where it can be reached by growing roots.

When European explorers discovered North America, they found that the whole of what is now the United States and Canada, from Labrador to beyond the Mississippi River, was covered with dense forests, with only a few clearings which the Indians had made, but of bewildering variety. As the interior was gradually opened up and mapped, the actual distribution and arrangement of the forests became much more clear. It was then seen that the forests were primarily divided into Eastern and Western, separated by the width of the Great Plains, in which there were no forests and trees were to be found growing along the watercourses. Confining attention to the United States, the Eastern Forest is subdivisible into (1) the Northern Forest, which covered New England, New York, and the lands adjacent to the Great Lakes. In this belt the predominant deciduous trees were maples, beeches, and birches, and, among the conifers, white pine, spruce, and hemlock. The Appalachian Mountains continued this type of forest far to the south, but these mountains are not high enough to rise above the temperate zone, and are wooded to their tops. (2) The Southern Forest covered the coastal plain of the Middle and Southern Atlantic and the Gulf States, and was largely coniferous; the long-leaf and the broad-leaf pines, with cedars and cypresses, were the predominating conifers, and oaks and the gums the principal deciduous kinds. (3) The Central Hardwood Forest filled the greater part of the Mississippi Valley from eastern Texas northward to the Northern Forest on both sides of the Appalachian Mountains, on the eastern side of which it covered the Piedmont Plateau. It is very rich in species, of which oaks, hickories, walnuts, chestnuts, and gums are the most abundant. West of the Mississippi, the boundary between forest and open plain is a very irregular, sinuous line, the wooded regions inclosing large grassy areas, which the early French explorers called *prairies*. The prairies were also found east of the river; nearly all of Illinois and a small part of Indiana were prairie land.

The Western Forest falls naturally into two parts. (1) The Rocky Mountain Forest is very much broken up, because the trees can grow only above a certain height on the mountain sides, which changes with the latitude; often the line at which the timber ceases, below as well as above, is as clearly marked as though drawn with a ruler; the upper limit ("timber line") is determined by temperature, the lower by moisture. In Arizona, for instance, the lower limit is 7,000 feet, and the upper limit 11,500 feet, above the sea. Wherever the land is sufficiently high, whether on the mountain ranges or the high plateaus, there the forest grows, often separated by long intervals from the next one and looking, on the map, like an archipelago. In South Dakota, on the Wyoming border, the Black Hills rise, an isolated mass, surrounded on all sides by the Great Plains, and they were once heavily wooded. Very often, as in the Coconino Forest of the Arizona Plateau, or in the Blue Mountains of eastern Oregon, the forests have little or no underbrush, the ground being carpeted with grass; the trees, well spaced apart, attain very great size, and these "park forests" are singularly beautiful.

The Western Forest, in both of its subdivisions, is preponderatingly made up of many species of coniferous trees, the deciduous trees playing but a very subordinate part. In the Rocky Mountain subdivision, the principal trees represented are the western yellow pine, Engelmann's spruce, and the lodgepole pine. The latter, as its name indicates, was very largely used by the Indians for the poles of their lodges or wigwams.

(2) The Pacific coast subdivision of the Western Forest extended from Alaska to southern California. Down to the boundary of the United States proper, and a little beyond in northern Montana, Idaho, and Washington, the two subdivisions are not distinguished. In Washington and Oregon the forest was originally continuous from the Cascade Mountains to the seashore, but in California it divides into two parts, one following the Coast Range down almost to San Francisco, and the other extending down the Sierra Nevada for two-thirds of the State's length; the central valley was not forested. The Pacific Coast forest is remarkable for the enormous size of its trees, far surpassing the growth to be found in any other part of the continent. The most characteristic of the Pacific Coast trees are the two sequoias of California, the redwoods and the big trees, the Douglas fir, the sugar pine, western hemlock, the giant arbor vitæ, and the Sitka spruce.

The northern limit of trees fluctuates very much, because it is not the Arctic cold that determines the boundary so much as the limitation of the season of growth. In the Arctic regions the season of growth begins in July and continues for about two months; if that period is shortened, trees cannot grow. In North America the northern limit of the forest follows the line of 50 degrees F. as the average temperature of the warmest month; north of that only dwarf trees can exist.

Between the European and the North American forests, the great difference consists in the much larger number of species of trees which America possesses. This is all the more remarkable because, at the present time, many more kinds of trees can be grown in England, with its mild winters, than in the northeastern United States, say, in the latitude of New York. Evidently, therefore, present climatic conditions do not account for the poverty of the European forests in species and the abundance of them in America, the explanation of which is to be sought in the events of the Glacial Epoch. Before that time, as is clearly demonstrated by the fossils, a very uniform belt of forest encircled the northern hemisphere. Many trees, such as magnolias, sassafras, tulip trees, liquidambars, sequoias, etc., which are now exclusively American, or confined to North America and the east coast of Asia, were then common in Europe also.

In both continents, the advancing ice sheets and refrigerating climate drove the forests southward. It may seem ridiculous to talk of the migration of forests, but it really happens nevertheless. If conditions favor, the seedlings at the border of the woods thrive, and each year sees new ones added, and thus the forest keeps extending in that direction so long as favorable conditions continue. Unfavorable conditions act in the opposite manner, killing off trees on the margin and causing the forest to shrink on that side. Thus, if the forest is shrinking on the north side and extending on the south, the effect is the shifting of the whole southward. It is, then, correct to say that the lowered temperature drove the forests southward in both continents, but in Europe the forests could not cross the Alps and the Pyrenees, or the Mediterranean coast between them. In effect, there is a continuous mountain wall from the Atlantic to the Caspian Sea, which caused the extermination of a great many species of trees which could not survive the severe winters of the Glacial Epoch and could not migrate to the south. In North America, on the other hand, the mountain ranges have a general north and south trend, leaving open the coastal plains and the vast central depression of the Mississippi basin. The forests were therefore free to retreat southward and return with the reestablishment of milder and more genial conditions. Thus, the number of species of forest trees, which was greatly reduced in Europe, underwent but little reduction in North America.

As the ice of Glacial times came southward, Arctic plants and animals came before it, reindeer and musk ox coming down as far as Kentucky, and the walrus to the coast of Georgia. When the climate ameliorated and the ice withdrew, the Arctic animals and plants retreated with it and, as the mountains were freed of ice, the northern species ascended them and established themselves there and, when climatic conditions were favorable, they have remained, though separated by hundreds of miles from their nearest congeners. Arctic animals and plants are found in the high Alps, and on the top of the White Mountains of New Hampshire grow many plants which are not found again till Labrador is reached.

Another curious fact concerning the distribution of trees in modern times is that the eastern coast of Asia is much more like the eastern side of North America than it is like the western coast of the same continent. There are numbers of trees found in Japan and China which are native in the eastern United States also, but not in any other part of the Old or New Worlds, though in a former age these trees went all around the earth.

Forests require abundant moisture in the soil, and are therefore confined to the regions of heavy precipitation, though there are wide limits within which the rainfall may fluctuate without rendering impossible the growth of forests. It makes little difference at what season of the year the precipitation occurs, provided that sufficient moisture be held in the soil to be available during the season of growth, and there is great variation in the amount needed by forests in warmer and colder climates. In southern Asia, for a vigorous growth of forest there must be at least 40 inches of rainfall, and in the tropics nearly twice that amount. In a warm climate, tropical or subtropical, the amount of moisture required by the forest is very much greater than in a cool climate, because of the immensely increased evaporation of water through the leaves at the higher temperatures. Yet even in the cool and moist climate of western Europe, the quantity of water which a forest takes from the soil and evaporates into the air, is surprisingly great; in that region a beech forest, composed of well-grown trees, evaporates about 354 tons of water per acre during the season of growth. The broad, soft leaves of the beech are very effective organs of evaporation, much more so than the hard, narrow needles of the conifers. In regions of cold winters a heavy snowfall often suffices to support forests, when the summer rains are very scanty, or even entirely lacking. Melting snow enters the ground very gradually and is stored up, when equally heavy rain would, for the most part, immediately rush off the surface into the nearest watercourse. The beautiful Coconino Forest, which covers about 6,000 square miles of the high plateau of Arizona, is made up almost entirely of the western yellow pine, which there grows to most stately and imposing size. The winter snow is very deep, which protects the soil against the penetration of the frost, and supplies the moisture needed in the growing season.

Trees require such large quantities of water because the mineral salts, such as potash, phosphates and the like, must be taken in through the roots in very dilute solution, and the excess of water can be disposed of only by evaporation through the leaves. In the scrubby forests of the dry tropics, where the rainfall is insufficient, elaborate structures appear to check and diminish evaporation. Some plants go so far as to get rid of their leaves entirely, or convert them into something which is very different in appearance and function. The barbed spines of a cactus are its leaves, little as they suggest such an origin. The dry forests of Africa pass into the "bush," as it is called both in Africa and Australia, or the "scrub," where the ground is covered more or less thickly with bushes, with occasional trees, but without grass or herbs. This sort of vegetation, which covers large areas in Africa, Australia, and South America, is not extensively displayed in the northern hemisphere. The chapparal of northern Mexico, Texas, and Arizona is, perhaps, the most typical instance of it; mimosa and other thorn bushes are its chief constituents, and it is characteristic of regions which are hot and dry, yet not altogether desert.

It was at one time widely believed that forests exerted an important effect upon climate, especially upon rainfall, and the obvious desiccation which such countries as Spain and Palestine have undergone has been attributed to the cutting off of their forests. More exact and extended observation has not confirmed this; in the lowlands the presence or absence of forests has no appreciable influence upon the rainfall; in hilly countries there may be a slight influence of the sort, but it has not been measured. Nevertheless, forests do have a modifying effect upon climate; they lower the temperature somewhat, and regulate the discharge of water, so that springs and streams in a forested area fluctuate less; they protect the soil against rainwash and in many places, especially those with steep slopes, the soil has all been washed away and the region ruined for agriculture after the removal of the protecting forest. Because of the great quantity of water which they evaporate, the planting of trees often assists materially in the draining of swamps and marshes, thus diminishing or destroying the breeding places of mosquitoes. The Australian tree, Eucalyptus, or blue gum, has been very extensively used, and with good results.

In the temperate zone, and to some extent also in the tropical, grasslands replace the forests when the supply of moisture is insufficient for the growth of trees. In our own Middle West, the transition from forest to grassland was, originally, a gradual one, the prairies expanding and breaking up the forest into isolated patches, until these ceased and only the grassy plain remained. The Great Plains and the plateau that lies to the west of the Rocky Mountains are typical grasslands, the luxuriance and thickness of the grasses diminishing westward as the rainfall decreases. In the semiarid regions the grasses are no longer able to cover the ground completely, but grow in scattered tufts and bunches; one sort of grass, which is most excellent feed for cattle and sheep because of its nutritive qualities, is called bunch grass, on account of its habit of growth. In the semiarid regions of the northern interior, west of the Rocky Mountains, the plateaus are very extensively covered with sagebrush, a low, sturdy bush, but the tufted grass continues to grow, though largely hidden from sight. In the north there is very little true desert, but in the trade-wind belt to the south, in Mexico and the adjoining parts of the United States, there are true deserts. The passage from forest to desert may be either through bushlands or through grasslands, the former method being especially characteristic of Australia and Africa, the latter of the temperate zone. In Europe, for example, all the western and central parts of the continent were originally forested, and even in Russia the forest covered the northern part of the country below the Arctic wastes, which were beyond the limit of trees. In the Russian forest belt the northern portion is of coniferous trees, the southern of oaks. Southward the forest passes gradually into the grassland of the steppes which cover all of southern Russia and extend into Asia beyond the Caspian Sea. In southeastern Europe the forest gives way to grasslands, and the latter pass into the deserts of Asia.

Grasslands in the southern hemisphere are most extensively displayed in the pampas of Argentina, where trees are entirely lacking; but in Patagonia, where the surface is very generally covered with coarse gravel, the grass gives way to a bushland, except in the river valleys. Desert as Patagonia seems to be, it is an excellent country for sheep.

Grasses do not evaporate such quantities of water, even proportionately, as trees do, and their roots do not penetrate so deeply into the soil; they therefore require moisture in the upper layers of the soil during their period of growth, which may be very brief. In the Great Plains, near the Rocky Mountains, the surface moisture is derived chiefly from the spring rains, and for a few weeks the country is brilliantly green, but with the coming of hot, dry weather, the grass fades and brown replaces the green. The grass does not merely wither, like the winter-killed grass of moist climates, but is a natural, self-cured hay, upon which the cattle and horses thrive and grow fat, as they do also in the Argentine pampas.

The Mediterranean region, including Mesopotamia in that term, has furnished the most important and widely spread of the modern cultivated plants; some of these came originally from the Far East, but the modern world received them by way of the Mediterranean countries, into which they were brought at various periods before the overthrow of the Roman Empire. Wheat, barley, and rice, most of our familiar vegetables and fruits, as well as flax and cotton, have had this history.

So far as the indigenous plants of North and South America are concerned, few besides the forest trees have much economic importance. Cultivated plants are carried all over the world and introduced wherever they can be grown satisfactorily, and thus our field and garden plants are almost all of Old World origin. America has contributed a number of plants that are valuable, nearly all from South America, potatoes, tomatoes, tobacco, Indian corn, pineapples, cocoa, and probably the sweet potato also.

The need of a scientific and effective forest policy is already pressing for solution. The example of Europe, especially of Germany, Austria, and France, has already shown the way. In these countries the forests are constantly maintained, but are, nevertheless, made to yield a steady supply of timber. This is accomplished by replacing every tree that is cut down with another newly planted, and thus an annual crop of trees is harvested without diminishing the forest.

The temperate zone of the southern hemisphere contains but little forest. In South America the broad plains on the Atlantic side of the Cordillera are grasslands, the Argentine pampas, or gravel-covered uplands, as in Patagonia. The rain forest on the west side of the mountains contains but a very little amount of useful timber. South temperate Africa and Australia are, for the most part, bare of forests and must import their timber, which they do chiefly from the Pacific coast of North America. The timber supply of the world must be principally derived from the northern hemisphere. The tropical forests yield valuable woods, such as bamboo, mahogany, and teak, which are most useful for certain particular purposes; but the great quantities of ordinary lumber, rough or finished, which the world constantly requires, the pine, spruce, cedar, cypress, oak, birch, etc., must long continue to come, as they do now, from the forests of the north temperate zone. Extremely valuable products, other than timber, are obtained from tropical forests, such as palm nuts, palm oil, rubber, cocoa, and quinine.

The grasslands are even more important to mankind than are the forests. When the rainfall is copious, or when water can be stored in quantities sufficient for irrigation, the grasslands are readily converted to agricultural uses, without the immense labor of clearing away the forest. The prairie States, such as Illinois and Iowa, have proverbially rich soils, and in the arid parts of the West the soil is extraordinarily fertile and, whenever it can be irrigated, gives fabulous returns.

When the drier portion of the Great Plains was still almost completely unoccupied by Americans, the so-called buffalo roamed over them in vast herds; and it occurred to some observant person that, if the buffalo could subsist through the winter on what feed they could obtain for themselves, domestic cattle would probably be able to do the same. When tried, the experiment proved successful, and so the ranching system, which the Spaniards had introduced into Mexico and Texas, was gradually extended northward over all the Great Plains up to the Canadian border and beyond it. A gigantic stock-raising industry was thus developed which was profitable and yet supplied the Eastern markets with beef at very low prices.

Several factors have combined to bring about an unwelcome change. In the first place, the land policy of the United States Government has always been consistently opposed to the formation of great holdings out of the public lands, and the Land Office would neither sell nor lease large areas to the cattlemen, nor permit them to fence in any part of the public domain. In the second place, the old cattle ranges have been very largely broken up by settlers who have bought land in 160-acre lots from the Government and fenced their holdings.

Much the same process is going on in the Argentine pampas as in our Great Plains; the grasslands, which have long supported vast herds of half-wild cattle, are being turned into fields of wheat and corn. Enough pasture remains, however, for an abundant supply of cheap beef, and great quantities of chilled meat are exported to England in refrigerator ships. A careful study of the areas which cannot be irrigated and are too dry for any other sort of farming will probably make possible the raising of live stock for many generations to come. A very large part of south and south-central Africa is grassland and, from present indications, much of it cannot be used for agriculture, because of the few streams, or natural sites for storage reservoirs. The chief obstacle to stock raising which has been encountered in south Africa is found in the diseases which attack cattle and horses there.

New Zealand and Australia raise sheep on a very large scale. In New Zealand the animals are bred principally for mutton, while Australia is the principal wool-raising region of the world.